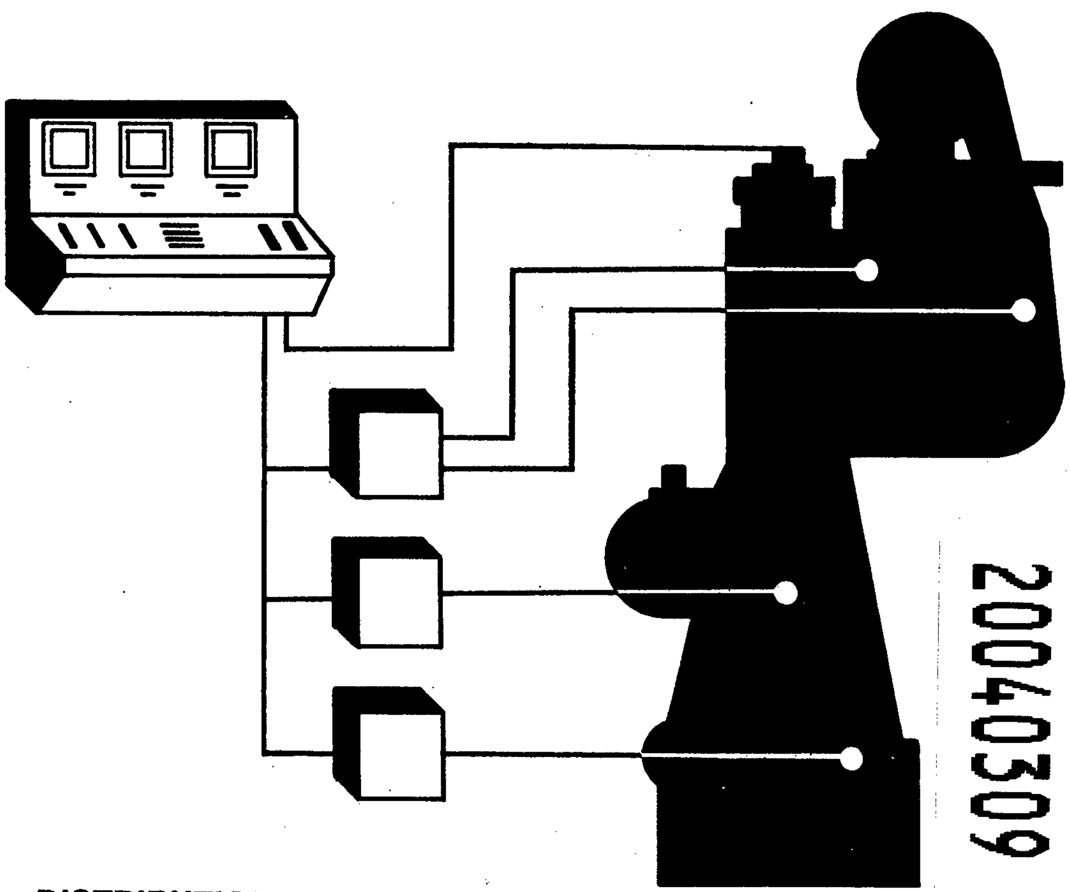
U.S. Department of Transportation
Maritime Administration

An Assessment of Performance and Condition Monitoring Requirements of Foreign Marine Diesel Propulsion Systems

FINAL REPORT



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16. Abstract (Limit: 200 words)

This report presents a synopsis of the requirements and recommended practices for diesel engine diagnostic, performance and condition monitoring systems for medium and slow speed diesel propulsion systems. The basis for the requirements, practices and recommendations presented is an extensive survey of foreign (European and Japanese) classification societies, diesel engine manufacturers, electronics systems manufacturers, and shipowners/operators. Included in the report are tabulated machinery parameters which are sensed for performance and condition monitoring purposes. The report concludes with recommendations for the application of performance and condition monitoring systems which can be used as a design guide by U.S. Flag owner/operators.

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Diesel Engine Condition Monitoring
Diesel Engine Performance Monitoring
Medium Speed Diesel
Slow Speed Diesel
Machinery Monitoring
Diesel Automation
Diesel Maintenance

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AN ASSESSMENT OF PERFORMANCE AND CONDITION MONITORING REQUIREMENTS OF FOREIGN MARINE DIESEL PROPULSION SYSTEMS

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Office of Research and Development
Washington, D.C. 20590

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<u>Classification Societies</u>

Bureau Veritas
Det Norske Veritas
Germanischer Lloyd
Lloyd's Register of Shipping
Nippon Kaiji Kyokai

<u>Electronics Systems Manufacturers</u>

Autronica A/S
Søren T. Lyngsø A/S
Mitsubishi Heavy Industries, Ltd.
NorControl

<u>Engine Manufacturers and Licensees</u>

Burmeister & Wain
Maschinenfabrik Augsburg-Nurnberg A.G. (M.A.N.)
Mitsubishi Heavy Industries, Ltd.
Mitsui Engineering & Shipbuilding Co., Ltd.
S.E.M.T. Pielstick
Stork Werkspoor
Sulzer Bros., Ltd.

<u>Shipowners/Operators</u>

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Navale et Commerciale Havraise Peninsulaire
Nedlloyd Fleet Services
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Shell International Marine Ltd.
Thor Dahl A/S
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The Norwegian Institute of Technology, (NTH), (The University of Trondheim)

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

Shipowners and operators are continually searching for new methods to operate their vessels more economically and reliably. Numerous factors, such as fuel quality, market conditions and operating costs have made these judgements difficult at best.

Today, as the United States faces the next decade with a commercial fleet becoming increasingly diesel powered, many of the past design, operational and practical considerations must be re-evaluated. One of the areas that must be carefully scrutinized is propulsion plant performance and condition monitoring, (PM/CM).

A good part of the expense in operating a diesel propulsion plant, unlike its steam counterpart, lies in the continual "grooming" and care of the diesel propulsion engine. In steam plants, normally, performance degradation is slow. Typically, considerable time passes before any severe drop in performance or component condition is noticed. This is usually not the case with diesel plants. Numerous critical pressures, temperatures, trends and wear rates must be continuously monitored to ensure a healthy and economical plant. At times, only a one or two percent deviation in a critical parameter may mean the difference between component failure and a sound engine or between a good fuel rate and a ten percent increase in consumption!

The traditional U. S. philosophy regarding performance and condition monitoring, (any maybe rightly so in the past), has been "If it's not broken - don't fix it." This stems from some hard-earned experience in steam plants. Many times, in the eagerness to "open and inspect," (e.g., a steam turbine), occasionally more consequential troubles were introduced than eliminated.

The present difficulty is that this "laissez-faire" practice courts disaster with today's high powered, highly loaded diesel propulsion plants. The economical and reliable operation of today's vessels require a day-by-day, week-by-week monitoring commitment to the main propulsion diesel.

The care and nurturing of a marine diesel plant is a continual process. It requires a sound monitoring, diagnostic and maintenance philosophy.

To this end, an assessment of the performance and condition monitoring requirements of Foreign Marine Diesel Engine Builders, Electronic Systems Manufacturers, Classification Societies and Vessel Owner/Operators was conducted under the sponsorship of the U. S. Department of Transportation,

Maritime Administration Office of Research and Development.

This report provides a synopsis of the recommended practices of the leading European and Japanese marine engine builders and electronics manufacturers, the requirements of the classification societies and the past and current practices and requirements of the vessel operators.

The report culminates in recommended guidelines and standards for the application of diesel performance and condition monitoring diagnostic systems to main propulsion, slow and medium speed diesel plants.

Using this report, the U. S. Flag vessel owner/operators can utilize the recommended guidelines when making engineering and operational judgements on the design and specifications of their own performance monitoring and/or condition monitoring systems.

1.1 Technical Approach

The basic approach to this assessment was a series of in-depth foreign surveys. The primary objective was the determination of the current practices, recommendations and requirements of the European and Japanese engine and electronics manufacturers, classification societies, and diesel vessel operators. The intent of these in-depth interviews was to address the complex interrelationship between both the design and operational requirements of performance and condition monitoring systems. In the cases of the engine manufacturers and electronics manufacturers, their current recommended practices were also solicited.

It should be emphasized that none of the equipment manufacturers have specific requirements per sé for condition or performance monitoring systems. These systems are considered optional and in excess of the basic monitoring and control requirements for the safe operation of the machinery as dictated by the manufacturers themselves, the classification societies and the operators. Therefore, while these systems serve to enhance the safety, operation, performance and maintenance of the power plant there are presently no absolute requirements for them. With respect to the classification societies, their requirements or rules, both explicit or implicit, relative to the shipboard application of these systems were investigated. Finally, the vessel operators were surveyed to determine their unique requirements and objectives for condition and performance monitoring systems.

Further, a detailed analytical review of the most recently published data on condition and performance monitoring was undertaken. This information, along with the data

obtained from the questionnaires and interviews, was comparatively analyzed and the interrelations of the specifications and standards were then prepared in a tabular format, where appropriate. All of this data forms the basis from which the application guidelines and recommended standards and specifications for U. S. diesel propelled vessels were developed.

The resultant recommended guidelines are not based solely on the pure technical aspects of condition and performance monitoring. Other non-technical requirements, such as crew skill level, Union manning requirements, trade route influences, maintenance, philosophy and vessel operating profiles as they might influence the application of diagnostic systems, were considered and are addressed in the report.

1.2 Performance Monitoring and Condition Monitoring Definitions

There are similarities between performance and condition monitoring systems to the degree of identical system components and monitored parameters. But there are in fact distinct differences both in the definition and objectives of each. Therefore, the following definitions are provided for clarification of these frequently misapplied terms.

1.2.1 Performance Monitoring

Diesel propulsion plant performance monitoring, (PM), as applied in this report, is defined as:

* The monitoring, indication and subsequent assessment, (either automatically or manually), of the operational efficiency and performance levels of the diesel propulsion engine and its respective subsystems.

The objectives of this form of performance monitoring are:

* To effect the efficient, economic and optimal operation of the diesel propulsion plant.

* To reduce the possibility of "off design" operation degrading both the individual components and the overall system reliability and service life.

1.2.2 Condition Monitoring

Diesel propulsion plant condition monitoring, (CM), with

its objectives as applied in this report, is defined as:

* The monitoring of component or system wear and degradation in order to predict scheduled maintenance or at least to avoid catastrophic failure. Condition monitoring is meant to supplement, not supplant, the traditional high/low limit alarm systems.

1.3 Summary of Findings and Recommendations

The findings and recommended guidelines for the successful application of performance and condition monitoring equipment to main propulsion diesel engines are summarized below. These recommendations represent a distillation of both the positive and negative experiences with performance and condition monitoring systems in the European and Japanese maritime communities over the past six to eight years.

The recommended performance and condition monitoring standards and specifications are a composite of the more successful programs developed and utilized by several foreign diesel operators. The diagnostic equipment and suggested practices detailed in this report supplement the conventional diesel instrumentation recommended in the NTIS publication "An Assessment of Automation and Control System Requirements of Foreign Marine Diesel Propulsion Systems," NTIS PB-81-198012.

1.3.1 Findings

During the initial investigations and in the course of the technical surveys it became immediately apparent that the use of large, centralized, diagnostic systems had proven to be cost prohibitive and less than effective in the past. Individual, dedicated subsystems appeared to be the most promising approach to diesel performance and condition monitoring.

In the mid to late 70's many elaborate predictive and diagnostic routines were developed to assist in diesel maintenance planning. Yet the success of these techniques usually rested on low accuracy conventional sensors or state-of-the-art but short lived transducers. Accurate and reliable field mounted sensors, carefully installed, were mentioned time and time again as mandatory prerequisites for any successful diesel monitoring system.

Most foreign vessel operators felt that the condition

monitoring of individual components was best suited to the large, slow speed diesels. Component replacement and stocking costs were quoted as being high and a substantial amount of labor is generally involved with any unscheduled slow speed engine downtime.

On the other hand, it appears that the medium speed, four stroke propulsion units potentially stand to benefit the most from the selective application of engine performance monitoring. These four stroke engines tend to operate in "off-design" conditions more often due to the lack of adequate conventional monitoring instrumentation. Additionally, individual combustion performance deviations are compounded by the large quantity of cylinders normally associated with these plants.

Although there was a great deal of disagreement regarding the actual means of accomplishing effective diesel monitoring, all of the participants stressed the importance of establishing an overall, systematic program. The performance and condition monitoring hardware was only one segment of an integrated "systems" type approach taken by the more successful operators. The following items are representative of a high quality, effective program.

* System design tailored to the particular propulsion plant and vessel.
* Conscientious and careful system installation and commissioning.
* Significant crew involvement with reasonable training.
* Effective follow-up via planned and condition based based maintenance programs.
* Independent "profit-center" approach to each vessel.

1.3.2 Recommendations

The guidelines and recommendations for effectively applying diagnostic monitoring systems to U. S. Flag diesel propelled vessels are divided into two distinct categories or phases.

* Condition Monitoring Recommendations
* Performance Monitoring Recommendations

Although these two areas overlap in many instances, Figure 1-1 illustrates the broad range of engine functions monitored

FIGURE 1-1

SUMMARY OF PERFORMANCE AND CONDITION MONITORING FUNCTIONS FOR SLOW AND MEDIUM SPEED MARINE DIESEL ENGINES

Slow Speed/Medium Speed Engine Functions	Performance Monitoring	Condition Monitoring
Cylinder Combustion Processes		
* Pressures	PM	CM
* Angles	PM	
* Outputs	PM	CM
Fuel Injection Processes		
* Pressures	PM	CM
* Angles	PM	
* Temperatures	PM	
Air/Gas Path Processes		
* Ambients	PM	
* Abs. and ΔPressures	PM	CM
* Abs. and ΔTemperatures	PM	CM
Cylinder Components		
* Rings		CM
* Pistons		CM
* Liners		CM
Air/Gas Path Components		
* Filters	PM	CM
* Coolers	PM	CM
* Turbochargers	PM	CM
* Exhaust Valves/Scavenging Ports		CM
Drive Train Bearing Components		
* Main Bearings		CM
* Crank Pin Bearings		CM
* Crosshead Bearings		CM
* Thrust Bearings		CM
* Camshaft Bearings		CM
Heat Exchanger Components		
* Main Coolers	PM	CM
* Auxiliary Coolers	PM	CM
Fuel Oil Delivery Components		
* Preheaters		CM
* Filters		CM
* Separators		CM
* Quality	PM	CM

within each area.

When applying these systems, the ship operator should first address engine condition monitoring. Vessel reliability is not a luxury. No amount of performance monitoring or fine tuning will resolve missed voyage schedules or unanticipated engine downtime due to component failures.

The following engine components should be addressed initially. They are ranked in approximate order of priority.

Medium Speed/Four Stroke Engines

* Main Bearings
* Turbochargers
* Crank Pin Bearings
* Exhaust Valves

Slow Speed/Two Stroke Engines

* Crosshead Bearings
* Cylinder Liners
* Turbochargers
* Pistons

After the overall vessel reliability has been addressed, the performance levels of the propulsion plant should then be assessed. More intensive monitoring in the two following areas is recommended for both slow speed and medium speed engines.

* Cylinder Combustion Processes
* Air/Gas Path Processes

The final guidelines listed below refer to the overall approach that the vessel operator should take to ensure an effective performance and condition monitoring installation. They should be addressed approximately in the order listed.

* Remember that the performance and condition monitoring hardware is only one tool in a systematic maintenance and monitoring program. The installation of sophisticated equipment without adequate company-wide follow-up in the form of data analysis and maintenance scheduling usually results in wasted time and money. The major investment is not in the hardware but in the implementation of an overall maintenance program.

* Identify specific objectives and technical guidelines prior to purchasing the equipment.

* Involve the engine builder and the electronics

manufacturer at the earliest stage possible.

* Spend resources on obtaining high quality, rugged equipment rather than on sophisticated state-of-the-art features.

* Incorporate unitized, modular subsystems rather than one large, centralized data processing system.

* Involve the operating engineers via in-house support and training. If the performance and condition monitoring equipment is envisioned as a diagnostic tool in an overall program rather than a cure-all, it will be effective and successful.

2.0 CONVENTIONAL APPROACHES TO PERFORMANCE AND CONDITION MONITORING

2.0 CONVENTIONAL APPROACHES TO PERFORMANCE AND CONDITION MONITORING

Over the years, numerous conventional methods have been developed to monitor the overall efficiency and condition of marine diesel propulsion plants. These methods have, for the most part, been based on manually obtained combustion process diagrams, visual inspections, and high-low limit alarms. These practices, although moderately reliable, all suffer from a common failing. They usually provide information after the fact. That is, when a catastrophic failure is imminent or a substantial degradation of performance has already occurred, the plant operator is then alerted. Another factor which diminishes the value of much of these conventional performance and condition monitoring techniques is the simple fact that a good deal of their repeatability and accuracy must ultimately rest with the skills and abilities of the individual diesel propulsion plant engineer.

In these times of high capital investment with steadily escalating operating costs, many of these conventional methods are being reevaluated.

The following outlines many of these traditional diagnostic methods and highlights some of their advantages and disadvantages. In cases where new technology is available it is so noted and then more fully described in subsequent sections.

For ready reference, a compilation of these performance and condition monitoring parameters, including alternate technologies, are contained in Table 2-1, Conventional Diagnostic Practices, pages 2-10 through 2-26.

2.1 Cylinder Combustion Processes

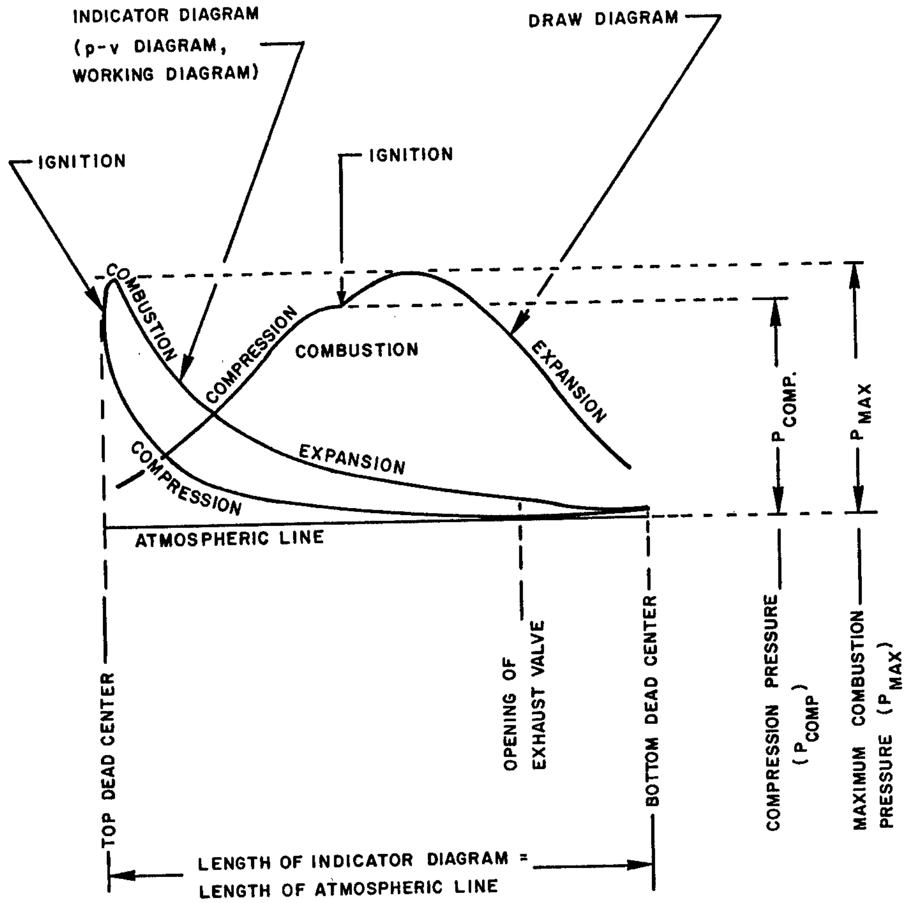
Manually obtained "Indicator" (pressure/volume), and "Draw" (pressure/time), diagrams have been utilized for many years to evaluate the thermodynamic combustion characteristics of marine diesel engines. Typical two stroke indicator diagrams and combustion parameters are shown in Figure 2-1, page 2-2.

In order to have any diagnostic or predictive value, these diagrams must be obtained by the operating engineer every fifty to one hundred running hours and generally more often if specific troubles are suspected. In practice, much of this information is rarely taken at less than monthly or bi-monthly intervals. The main difficulties seem to focus on the following items:

* Excessive time required to take reasonably representative readings.

FIGURE 2-1

TYPICAL TWO STROKE COMBUSTION PARAMETERS
(INDICATOR AND DRAW DIAGRAMS)
(REFERENCE 1)



* P_{max} ....Maximum Cylinder Pressure

* P_{comp} ....Compression Pressure

* P_{exp} ....Expansion Pressure

* αP_{max} ....Angle/Time of P_{max}

* αP_{comp} ....Angle/Time of P_{comp}

* Excessive time needed to interpret diagrams.

* Questionable repeatability and accuracy.

On a modern, high horsepower, multi-cylinder engine it may require as much as six to eight hours to record and adequately interpret these combustion parameters. The recent development of high temperature, piezoelectric, combustion pressure transducers and microprocessor analyzing units have made the acquisition and evaluation of cylinder combustion data much more practical and reliable.

2.2 Fuel Injection Processes

Additional parameters which influence the performance of the diesel plant include the fuel oil injection physical and thermodynamic processes. This not only includes the individual fuel pumps, fuel valves and associated camshafts, but the thermal loading within the combustion chamber as well. With conventional instrumentation, diagnostic information concerning these functions must be gathered from secondary parameters such as exhaust temperatures and the previously mentioned pressure/volume and pressure/time diagrams. In practice, this results in a "component replacement" type of diagnostic program. If a component is suspect, it is either replaced with a new unit or removed from the engine and recalibrated on a test stand.

Recently a new generation of piezoelectric, high pressure (1,500 bar) high temperature (350^{o}C) pressure transducers and microprocessor analyzing units, similar to those mentioned earlier for combustion parameters, have been developed to monitor these fuel oil injection processes directly.

Complimenting the above, new thermal monitoring techniques centered around the combustion chamber and the cylinder covers have been recently employed to further evaluate the combustion and injection characteristics.

2.3 Air and Gas Path Processes

Monitoring of this subsystem has traditionally been concerned with the following components:

* Scavenging Air Filters

* Turbo-Compressors

* Charge Air Coolers

* Scavenging Ports/Valves

* Exhaust Turbines

* Stack Components

The acquisition and evaluation of accurate data regarding these components has been, and still is, difficult. The performance and condition assessment of these systems involve the monitoring of extremely small differential pressures and relatively high absolute temperatures. Also, much of this data is dependent on highly variable aerodynamic flow patterns within the system.

The conventional instrumentation is usually not accurate enough nor is it sufficiently stable and drift free to provide meaningful diagnostic information. Many times in the past, for example, trend analysis plots have been methodically, if unknowingly, monitoring the drift of the instruments rather than the condition of the process.

Fortunately, a relatively high level of performance can be maintained for these subsystems with regularly scheduled, calendar type maintenance. The coolers, filters, and turbine and compressor blading being the key elements which are systematically maintained.

2.4 Cylinder Components

In the past, conventional cylinder component monitoring has been relegated exclusively to visual inspections and measurements conducted during scheduled or unscheduled engine overhauls. This of course usually results in the repair or replacement of components either too soon or too late. This lack of "on-line" knowledge concerning component wear and the uncertainty of its effect on the overall propulsion plant efficiency obviously results in a highly subjective, crisis oriented, maintenance schedule.

Even with today's technology, many of these components can still only be examined during overhaul. But numerous new developments such as piston ring induction sensors and liner wear probes have the potential for making many maintenance judgments less subjective.

2.5 Drive Train Bearing Components

Drive train bearing components are some of the most highly loaded and troublesome components in the marine diesel propulsion plant. They are inaccessible during operation and difficult to monitor. When problems arise they are usually major in nature and have the potential of stopping the vessel.

As a minimum, most conventional diesel propulsion plants have an oil mist detector system installed which monitors the opacity of the crankcase vapors. As the temperature of the oil rises a greater portion of the oil is vaporized and the density of the oil mist is increased. This increase in oil mist density signals an excessive bearing temperature rise. In practice, these standard monitoring systems are a classic example of the presentation of too little information, too late.

Lately, there has been much activity in this field but a good deal of the developmental work is still that - developmental, not practical. However, there are numerous techniques available to the operator. Various oil return-flow temperature monitoring schemes, bearing shell metal temperature sensors, and non-contact/magnetic field/thermistor based/wireless bearing temperature systems have been developed.

2.6 Main Engine and Auxiliary Heat Exchangers

Conventional differential temperature monitoring has been utilized in assessing the performance of heat exchangers for numerous years. Performance degradation and failure modes for these components usually do not result in catastrophic failures. A more typical occurrence usually involves the steady and predictable decline of heat transfer ability and performance characteristics. There are pros and cons of more sophisticated monitoring schemes for these components as compared to the traditional use of local thermometers.

2.7 Information Gathering, Processing and Display

As previously discussed, the majority of conventional engine performance and condition monitoring data has been manually gathered and processed. The evaluation and analysis of this information has also been traditionally performed by the operating engineers.

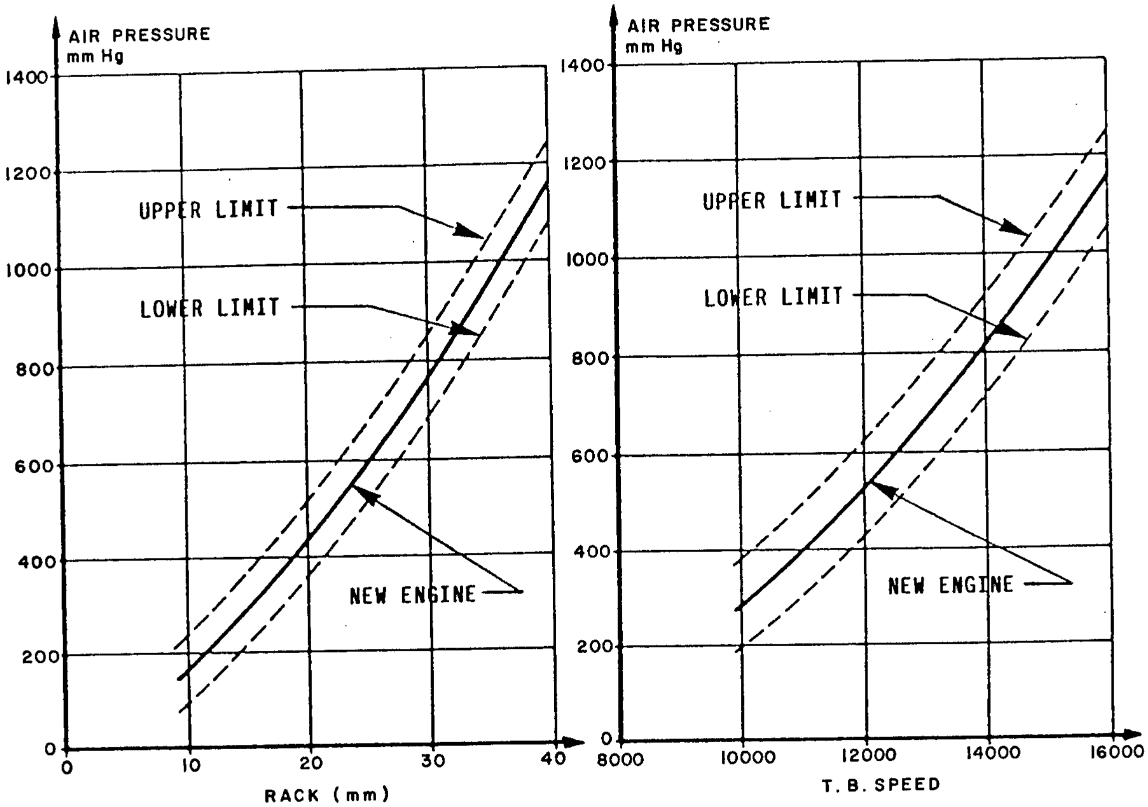
Indicator and draw diagrams, as shown earlier in Figure 2-1, are representative of manually gathered data. This information is, of course, supplemented by engine room log sheets.

As to the evaluation or management of this information, the conventional methods have usually included manual calculations plus trend plotting on graphical, time based scales. Test bed data, time based deviation charts, and parameter relationships for typical pressures and temperatures are shown in Figure 2-2, 2-3 and 2-4.

FIGURE 2-2

MEDIUM SPEED DIESEL, TYPICAL PARAMETER RELATIONSHIP PLOT

RELATIONSHIP BETWEEN AIR PRESSURE AND FUEL RACK POSITION OR TURBO BLOWER SPEED FOR THE DETERMINATION OF SUPERCHARGING SYSTEM CONDITION (REFERENCE 2)



The difficulty in applying graphic trend analyses has usually been encountered in the "normalization" or "standardization" of the observed information. It is vital that only data which have been adjusted to a common baseline be compared.

It should be noted that even the new technologies, (e.g., microprocessors, trend line calculations, etc.), suffer from these same drawbacks. Although it sometimes appears as if these new methods, such as digital displays, provide more accurate data, in fact, this at times is a case of better resolution and not better accuracy.

In computerized trend plotting and maintenance prediction, the accuracy of this standardized data depends primarily on the adequacy of the internal mathematical models or algorithms. If these programs accurately replicate the physical and thermodynamic processes of the particular diesel in question, the displayed output will be credible. If the

FIGURE 2-3
SLOW SPEED DIESEL, TYPICAL TIME BASE DEVIATION CHART EXHAUST TEMPERATURE
(REFERENCE 1)

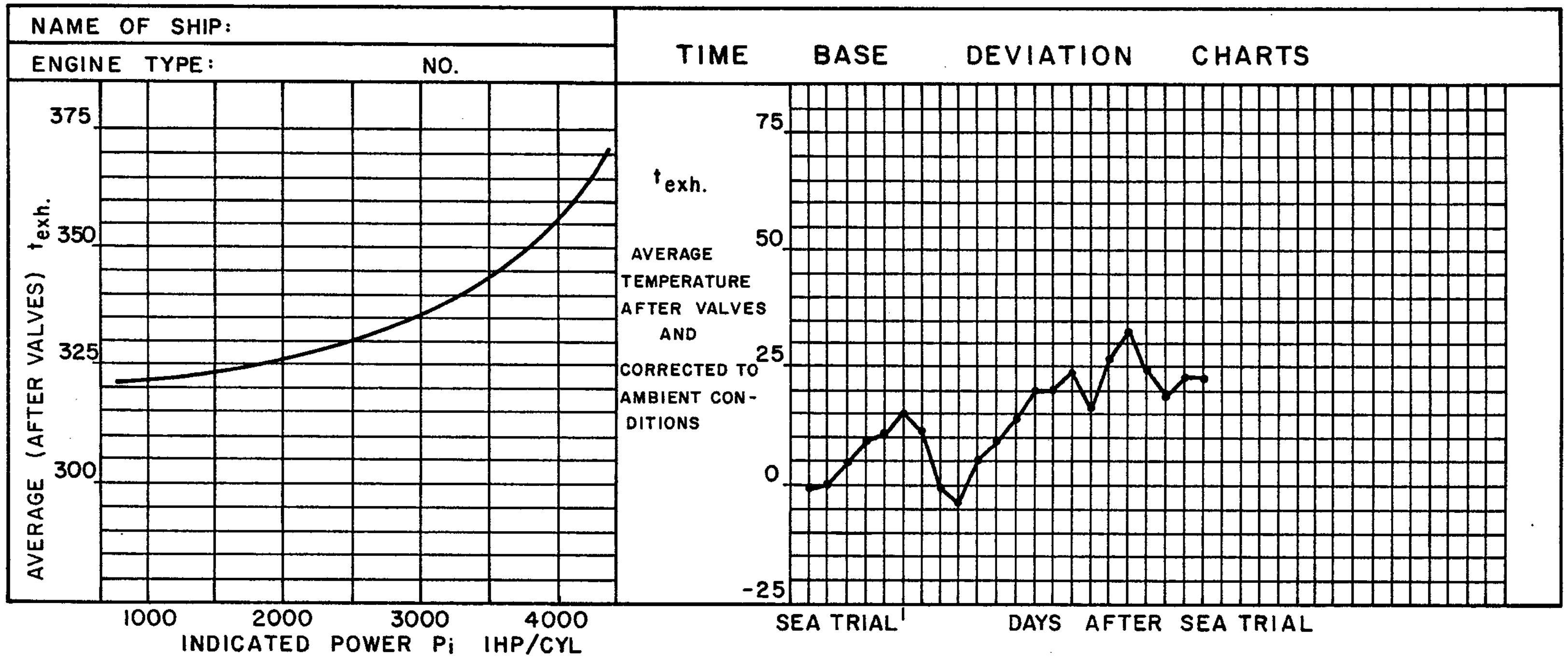
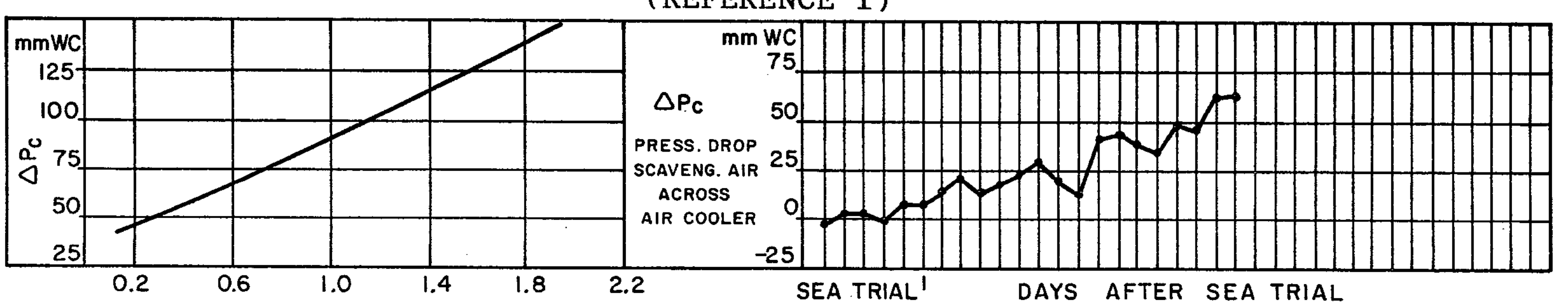


FIGURE 2-4
SLOW SPEED DIESEL, TYPICAL TIME BASE DEVIATION CHART
PRESSURE DROP ACROSS AIR COOLER
(REFERENCE 1)



mathematical models are poor approximations of these processes, then the output data becomes less usable.

As to the new techniques utilized today in gathering, processing, and displaying this information the following technologies are presently available.

Analog, digital and multiplex data transmission schemes have all been employed. Microprocessors are routinely utilized for calculating mean indicated pressures, indicated horsepowers, specific fuel oil consumptions, and apparent rates of heat release. Also included are trend line calculations and maintenance prediction features.

Display options include digital readouts, oscilloscopes, CRT's, plotters, printers, and alphanumeric type monitors. All of these approaches have been used with varying degrees of success.

2.8 Use of Tables

As previously stated, the following table is a compilation of key performance and condition monitoring parameters. The tables are conveniently organized by subsystem with each typically measured parameters within each subsystem identified. Also noted is whether the parameter is monitored for performance or condition purposes or both, where appropriate. Finally, the traditional or conventional methods of monitoring and/or data acquisition are identified, and where new technological approaches are available they are provided.

Table 2-1 addresses both slow speed and medium speed diesel engines since with only a few exceptions, the measured parameters for each engine type are essentially identical. Figure 2-5 provides an explanation of the abbreviations used in these tables.

FIGURE 2-5

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 2-1

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
AN	Anemometer	PG	Pressure Gauge
CALC.	Calculated	PP	Proximity Probe
CM	Condition Monitoring	RE	Rotary Encoder
DI	Dial Indicator	RTD	Resistance Temperature Detector
DRAW CARD	Pressure/Time Diagram	SG	Strain Gauge
DT	Displacement Transducer	TACH.	Tachometer
ESM	Electronic Smoke Detector	T/C	Turbocharger
GR. TACH.	Geared Tachometer	TC	Thermocouple
HYG	Hygrometer	TFR	Thin Film Resistor
IND. CARD	Indicator Card (PV)	TM	Torque Meter
LOG	Entered in Log Book	TG	Temperature Gauge
MAN	Manometer	TR	Thermistor
MIP	Mean Indicated Pressure	WTR	Wireless Thermistor
MP	Micro Processor	Δ	Differential
MPP	Magnetic Proximity Probe	/	or
Not Avail.	Not Available	+	and
PEPT	Piezoelectric Pressure Transducer	PM	Performance Monitoring

Table 2-1
- Conventional Diagnostic Practices -
Including Newly Available Technologies

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
1	CYLINDER COMBUSTION PROCESSES	P_{mi}/or MIP	MEAN INDICATED PRESSURE (per cylinder)	X	X	Ind. Card	PEPT & MP
2							
3		P_{max}	MAXIMUM OR FIRING PRESSURE (per cylinder)	X	X	Draw Card	PEPT & MP
4		P_{comp}	COMPRESSION PRESSURE (per cylinder)	X	X	Draw Card	PEPT & MP
5		P_{exp}	EXPANSION PRESSURE (per cylinder)	X	X	Draw Card	PEPT & MP
6							
7		$\propto P_{max}$	ANGLE OR TIME OF P_{max} (per cylinder)	X	–	Draw Card	PP/RE
8		$\propto P_{comp}$	ANGLE OR TIME OF P_{comp} (per cylinder)	X		Draw Card	PP/RE
9							
10		RPM	SPEED AT ENGINE FLYWHEEL	X	---	GR Tach	PP/RE
11		T/BHP	TORQUE/BHP AT ENGINE (value, method & location)	X	X	Fuel Rack/ TM	MIP
12		P_{scav}	SCAVENGING BELT AIR PRESSURE	X	X	PG/MAN	PT

Table 2-1
- Conventional Diagnostic Practices -
Including Newly Available Technologies

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
13	FUEL OIL INJECTION PROCESSES	POS & % DROOP	FUEL GOVERNOR POSITION AND % SPEED DROOP	X	--	Visual	---
14		INDEX	FUEL PUMP INDEX (per cylinder)	X	--	Visual	---
15							
16		Tcyl cover	CYLINDER TOP COVER TEMPS (per cylinder)	X	X	Not Avail.	Imbedded TC
17		P_{rise}	PRESSURE RISE PRIOR TO OPENING OF INJ. VLV (per cylinder)	X	X	Not Avail.	PEPT/ SG
18		P_{injo}	DYNAMIC OPENING PRESS OF INJ. VLV (per cylinder)	X	X	Not Avail.	PEPT/ SG
19		P_{injm}	MAXIMUM INJECTION PRESSURE (per cylinder)	X	X	Not Avail.	PEPT/ SG
20							
21		T_{injo}	TIME OF OPENING OF INJECTION VLV (per cylinder)	X	X	Not Avail.	PEPT/ SG
22		L_{injo}	LENGTH OF OPENING OF INJECTION VLV (per cylinder)	X	X	Not Avail.	PEPT/ SG
23							
24							

Table 2-1

- Conventional Diagnostic Practices -

Including Newly Available Technologies

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
25	AIR & GAS PATH PROCESSES						
26		P_{baro}	ENGINE ROOM BAROMETRIC PRESSURE	X	---	MAN	---
27							
28		$T_{E.R.}$	ENGINE ROOM AMBIENT TEMPERATURE	X	---	TG	---
29							
30		H_{rel}	ENGINE ROOM RELATIVE HUMIDITY	X	---	HYG	---
31							
32		ΔP_{air}	AIR PRESSURE DROP ACROSS T/C SCAV INLET FILTER (per T/C)	X	X	Δ PG/ MAN	Δ PT
33							
34		$P_{compr\ inlet}$	T/C COMPRESSOR INLET SUCTION PRESSURE (per T/C)	X	---	ABS/PG MAN	ABS/PT
35		ΔP_{TC}	AIR PRESSURE DROP ACROSS T/C COMPRESSOR HOUSING (per T/C)	X	X	Δ PG/ MAN	Δ PT
36		Pcomp outlet	AIR PRESSURE AFTER T/C COMPRESSOR (per T/C)	X	---	PG/ MAN	PT

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ITEM	SUB SYSTEM	MEASURED PARAMETER: SYMBOL	MEASURED PARAMETER: DESCRIPTION	TYPE OF MONITORING: PM	TYPE OF MONITORING: CM	CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
37	AIR & GAS PATH PROCESSES	$P_{sw\ in}$	SEA WATER PRESSURE AT INLET TO COOLER	---	X	PG	---
38							
39		ΔP_{air}	AIR PRESSURE DROP ACROSS CHARGE AIR COOLER (per cooler)	X	X	ΔPG/MAN	ΔPT
40		P_{scav}	SCAVENGING BELT AIR PRESSURE	X	---	PG/MAN	PT
41							
42		$P_{turb\ inlet}$	EXHAUST GAS PRESSURE BEFORE TURBINE (per T/C)	X	X	PG	PT
43		$P_{turb\ outlet}$	EXHAUST GAS PRESSURE AFTER TURBINE (per T/C)	X	X	PG/MAN	PT
44							
45		$P_{into\ boiler}$	EXHAUST GAS PRESSURE BEFORE WASTE HEAT BOILER	X	X	PG/MAN	PT
46		P_{out}	EXHAUST GAS PRESSURE AFTER WASTE HEAT BOILER	X	X	PG/MAN	PT
47		$\%CO_2$	EXHAUST GAS PERCENT CO_2	X	---	Gas Analysis	---
48		--	EXHAUST GAS CONDITION (opacity, etc.)	X	---	Visual	ESM

Table 2-1
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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER: SYMBOL	MEASURED PARAMETER: DESCRIPTION	TYPE OF MONITORING: PM	TYPE OF MONITORING: CM	CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
49	AIR & GAS PATH PROCESSES	$T_{air\ in\ comp}$	AIR TEMP AT INLET TO T/C COMPRESSOR	X	X	TG/RTD	---
50		$T_{air\ out\ comp}$	AIR TEMP AT OUTLET OF T/C COMPRESSOR (per T/C)	X	X	TG/RTD	---
51							
52		$T_{air\ in\ cooler}$	AIR TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	X	X	TG/RTD	---
53		$T_{air\ out\ cool.}$	AIR TEMP AT OUTLET OF CHARGE AIR COOLER (per cooler)	X	X	TG/RTD	---
54							
55		$T_{sw\ in\ cooler}$	SEA WATER TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	X	X	TG/RTD	---
56		$T_{sw\ out\ cooler}$	SEA WATER TEMP AT OUTLET FROM CHARGE AIR COOLER (per cooler)	X	X	TG/RTD	---
57							
58		T_{scav}	SCAVENGING AIR BELT TEMPERATURE	X	X	TG/RTD	---
59							
60							

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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
61	AIR & GAS PATH PROCESSES	$T_{exh.\ indiv.}$	EXHAUST GAS TEMP AFTER CYLINDERS (individual)	X	X	TC	---
62		$T_{exh\ mean}$	EXHAUST GAS TEMP AFTER CYLINDERS (mean)	X	X	TC	---
63		$T_{exh\ dev}$	EXHAUST GAS TEMP AFTER CYLINDERS (max. deviation)	X	X	TC	---
64							
65		$T_{exh\ to\ turb}$	EXHAUST GAS TEMP BEFORE TURBINE (per T/C)	X	X	TC	---
66		$T_{exh\ out\ turb}$	EXHAUST GAS TEMP AFTER TURBINE (per T/C)	X	X	TC	---
67		T_{in}	EXHAUST GAS TEMP BEFORE WASTE HEAT BOILER	X	X	TC	---
68		T_{out}	EXHAUST GAS TEMP AFTER WASTE HEAT BOILER	X	X	TC	---
69							
70							
71							
72							

Table 2-1
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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
73	CYLINDER COMPONENTS (RINGS)	---	PISTON RING COLLAPSE	–	X	Visual	MPP
74		---	PISTON RING BREAKAGE	–	X	Visual	MPP
75		---	PISTON RING STICKING	–	X	Visual	MPP
76		mm	PISTON RING WEAR	–	X	Visual	MPP
77							
78		HRS	PISTON RING OPERATING HOURS	–	X	Log	---
79	CYLINDER COMPONENTS (PISTONS)	---	PISTON GROOVE CONDITION	–	X	Visual	---
80		mm	PISTON GROOVE WEAR	–	X	Visual	---
81		---	PISTON CROWN CONDITION	–	X	Visual	---
82		mm	PISTON CROWN WEAR	–	X	Visual	---
83							
84		HRS	PISTON OPERATING HOURS	–	X	Log	---

Table 2-1
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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
85	CYLINDER COMPONENTS - LINERS	T_{Liner} (upper)	CYLINDER LINER TEMP (upper)	–	X	Not Avail.	Imbedded TC
86							
87		T_{Liner} (lower)	CYLINDER LINER TEMP (lower)	–	X	Not Avail.	Imbedded TC
88		T_{scuff}	CYLINDER LINER TEMP (scuffing)	–	X	Not Avail.	Surface TC
89							
90		---	CYLINDER LINER CONDITION	–	X	Visual	---
91		mm	CYLINDER LINER WEAR	–	X	Visual	Imbedded TFR
92		HRS	CYLINDER LINER OPERATING HOURS	–	X	Log	---
93							
94		$Kg/_{day}$	CYLINDER LUBE OIL CONSUMPTION	–	X	Sounding	---
95		$Kg/_{day}$	ENGINE LUBE OIL CONSUMPTION	–	X	Sounding	---
96							

Table 2-1
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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
97	AIR/GAS PATH COMPONENTS (TURBOCHARGERS)	RPM	TURBOCHARGER SPEED (per T/C)	X	X	Tach	---
98		mils	TURBOCHARGER VIBRATION LEVEL (per T/C)	–	X	Vibr. Mon.	---
99							
100		$T_{LO\ in}$	TURBOCHARGER LUBE OIL INLET TEMP (per T/C)	–	X	TG/RTD	---
101		$T_{LO\ out}$	TURBOCHARGER LUBE OIL OUTLET TEMP (per T/C)	–	X	TG/RTD	---
102		$P_{LO\ in}$	TURBOCHARGER LUBE OIL INLET PRESSURE (per T/C)	–	X	TG/RTD	---
103							
104	AIR/GAS PATH COMPONENTS (EXHAUST VALVES)	mm	SPINDLE GUIDE CLEARANCES	–	X	Visual	---
105		mm	RING CLEARANCES	–	X	Visual	---
106		mm	SPINDLE WEAR	–	X	Visual	---
107		mm	SEAT WEAR	–	X	Visual	---
108							

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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
109	AIR/GAS PATH COMPONENTS (EXHAUST VALVES)	---	SEAT BURNING	–	X	Visual	---
110		---	SPRING CONDITION	–	X	Visual	---
111							
112		mm	HYDRAULIC LINER DIAMETER	–	X	Visual	---
113		mm	ROLLER CLEARANCES	–	X	Visual	---
114		---	CAM & ROLLER SURFACES	–	X	Visual	---
115		---	HOUSING & GUIDE SURFACES	–	X	Visual	---
116							
117		HRS	OPERATING HOURS	–	X	Log	---
118							
119							
120							

Table 2-1
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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
121	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	MAIN BEARING OIL OUTLET TEMPERATURE	–	X	Oil Mist Monitor	RTD
122		T_{brg}	MAIN BEARING HOUSING AND SHELL TEMPERATURE	–	X	Oil Mist Monitor	WTR
123		mm	MAIN BEARING CLEARANCES	–	X	Visual	DT
124							
125		$T_{oil\ out}$	CRANK PIN BEARING OIL OUTLET TEMPERATURE	–	X	Oil Mist Monitor	RTD
126		T_{brg}	CRANK PIN BEARING HOUSING AND SHELL TEMPERATURE	–	X	Oil Mist Monitor	WTR
127		mm	CRANK PIN BEARING CLEARANCES	–	X	Visual	---
128							
129		$T_{oil\ out}$	CROSSHEAD BEARING OIL OUTLET TEMPERATURE	–	X	Oil Mist Monitor	RTD
130		T_{brg}	CROSSHEAD BEARING HOUSING AND SHELL TEMPERATURE	–	X	Oil Mist Monitor	WTR
131		mm	CROSSHEAD BEARING CLEARANCES	–	X	Visual	---
132		mm	GUIDESHOE CLEARANCES	–	X	Visual	---

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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
133	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	THRUST BEARING OIL OUTLET TEMPERATURE	–	X	Oil Mist Monitor	RTD / TR
134		T_{brg}	THRUST BEARING PAD METAL TEMPERATURE	–	X	RTD	---
135		mm	THRUST BEARING PAD CLEARANCES	–	X	Visual	---
136		mm	CAMSHAFT BEARING CLEARANCES	–	X	Visual	---
137		ppm	CRANKCASE OIL MIST DETECTION	–	X	Oil Mist Monitor	---
138		mm	CONTROL DRIVE GEAR BACKLASH	–	X	Visual	---
139		---	LUBE OIL ANALYSIS (Ferrography, etc.)	–	X	Lab Analysis	On Line Analysis
140							
141		mm	CRANKSHAFT MAIN BEARING DISPLACEMENT	–	X	Bridge Gauge	DT
142							
143		mm	CRANKWEB DEFLECTION ANALYSIS	–	X	DI	---
144							

Table 2-1
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Including Newly Available Technologies

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER: SYMBOL	MEASURED PARAMETER: DESCRIPTION	TYPE OF MONITORING: PM	TYPE OF MONITORING: CM	CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
145	HEAT EXCHANGER COMPONENTS - MAIN	$\Delta T_{F.W.}$	JACKET WATER F.W. TEMP. Δ ACROSS JACKET WATER COOLER	X	X	TG/RTD	---
146		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS JACKET WATER COOLER	X	X	TG/RTD	---
147							
148		$\Delta T_{F.W.}$	PISTON COOLING F.W. TEMP. Δ ACROSS PISTON COOLER	X	X	TG/RTD	---
149		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS PISTON COOLER	X	X	TG/RTD	---
150							
151		$\Delta T_{L.O.}$	MAIN LUBE OIL TEMP. Δ ACROSS LUBE OIL COOLER	X	X	TG/RTD	---
152		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS LUBE OIL COOLER	X	X	TG/RTD	---
153							
154		$\Delta T_{L.O.}$	TURBOCHARGER LUBE OIL TEMP. Δ ACROSS T/C LUBE OIL COOLER	X	X	TG/RTD	---
155		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS T/C LUBE OIL COOLER	X	X	TG/RTD	---
156							

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Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER SYMBOL	MEASURED PARAMETER DESCRIPTION	TYPE OF MONITORING PM	TYPE OF MONITORING CM	CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
157	HEAT EXCHANGER COMPONENTS - MAIN	$\Delta T_{L.O.}$	CAMSHAFT LUBE OIL TEMP. Δ ACROSS CAMSHAFT L.O. COOLER	X	X	TG/RTD	---
158		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS CAMSHAFT L.O. COOLER	X	X	TG/RTD	---
159							
160		---	FRESH WATER COOLING ADDITIVE ADEQUACY	-	X	Analysis	---
161	HEAT EXCHANGER COMPONENTS - AUXILIARY	$\Delta T_{F.W.}$	AUX. ENG. CYL. FRESH WATER TEMP. Δ ACROSS COOLER	X	X	TG/RTD	---
162		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS FRESH WATER COOLER	X	X	TG/RTD	---
163							
164		ΔT_{air}	AUX. ENG. CHARGE AIR TEMP. Δ ACROSS CHARGE AIR COOLER	X	X	TG/RTD	---
165		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS CHARGE AIR COOLER	X	X	TG/RTD	---
166							
167		$\Delta T_{L.O.}$	AUX. ENG. LUBE OIL TEMP. Δ ACROSS LUBE OIL COOLER	X	X	TG/RTD	---
168		$\Delta T_{S.W.}$	SALT WATER TEMP. Δ ACROSS LUBE OIL COOLER	X	X	TG/RTD	---

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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
169	FUEL OIL DELIVERY COMPONENTS	$T_{F.O.\ in}$	FUEL OIL TEMP. BEFORE PRE-HEATERS	X	X	TG	---
170		$T_{F.O.\ visc}$	FUEL OIL TEM. AFTER PRE-HEATERS AT VISCOSIMETER	X	X	TG	---
171		$T_{F.O.\ in}$	FUEL OIL TEMP. AT ENGINE INLET	X	-	TG	---
172							
173		$P_{in\ fltr}$	FUEL OIL PRESSURE BEFORE FILTERS	-	X	PG	---
174		$P_{out\ fltr}$	FUEL OIL PRESSURE AFTER FILTERS AT ENGINE INLET	X	X	PG	---
175							
176		$Q_{F.O.}$	FUEL OIL CONSUMPTION/FLOW RATE	X	X	Sounding/ Flow Mtr	Mass Flow Mtr
177							
178		$T_{in\ sep}$	FUEL OIL TEMPERATURE BEFORE SEPARATOR	X	X	TG	---
179		$Q_{\%\ flow}$	FUEL OIL PERCENT THROUGHPUT AT SEPARATORS	X	X	Visual	Flow Mtr
180							

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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
181	FUEL OIL DELIVERY COMPONENTS	cSt.	FUEL OIL VISCOSITY AT 50^{o}C	X		Lab Analy SPCL	---
182		S.G/ρ	FUEL OIL SPECIFIC GRAVITY OR DENSITY	X		Lab Analy SPCL	---
183		%S	FUEL OIL SULFUR CONTENT	X		Lab Analy SPCL	---
184		%V	FUEL OIL VANADIUM CONTENT	X		Lab Analy SPCL	---
185		h_i	FUEL OIL HEATING VALUE	X		Lab Analy SPCL	---
186							
187	VESSEL FACTORS - DESIGN	Ft./m	DRAFT (Fwd/Aft) BALLAST	X	X	Design	---
188		Ft./m	DRAFT (Fwd/Aft) LADEN	X	X	Design	---
189		DWT	DEADWEIGHT/BALLAST	X	X	Design	---
190		DWT	DEADWEIGHT/LADEN	X	X	Design	---
191		Knts	SPEED (Laden/Light)	X	X	Design	---
192		mm	PROPELLER PITCH	X	X	Design	---

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ITEM	SUB SYSTEM	MEASURED PARAMETER		TYPE OF MONITORING		CONVENTIONAL METHOD	NEWLY AVAILABLE TECHNOLOGY
		SYMBOL	DESCRIPTION	PM	CM		
193	VESSEL FACTORS - EXTERNAL	FT/m	DRAFT (Fwd & Aft)	X	---	Visual	---
194							
195		knts	SPEED (by log)	X	---	Log	---
196		knts	SPEED (over ground)	X	---	Plot	---
197		min^{-1}	RPM (shaft/engine)	X	---	Tach	---
198		%	PROPELLER SLIP	X	---	Calc	---
199							
200		FT/m	WATER DEPTH	X	---	Dopp Depth	---
201		#	SEA STATE	X	---	Visual	---
202		DIR	SEA DIRECTION	X	---	Visual	---
203		#	WIND FORCE	X	---	AN	---
204		DIR	WIND DIRECTION	X	---	AN	---

3.0 ENGINE MANUFACTURERS AND LICENSEE RECOMMENDED PRACTICES

3.0 ENGINE MANUFACTURERS AND LICENSEE RECOMMENDED PRACTICES

In order to provide a baseline for the determination of requirements for marine diesel plant diagnostic systems, a series of interviews were conducted with the major European and Japanese engine builders. These in-depth interviews were undertaken to define each engine manufacturer's current recommended practices regarding the monitoring of diesel performance levels and component conditions.

Manufacturers of both slow speed/two stroke and medium speed/four stroke engines were interviewed. All manufacturers were familiar with the latest developments within the performance and condition monitoring fields. In fact, certain engine builders offered their own diagnostic systems.

As a result of these discussions it appeared that the recommended practices and their respective matrices should represent, not what equipment was available from each manufacturer, but actually what each engine builder recommended. The following sections represent the engine builders' recommendations as a result of their experience and their subjective and implicit engineering judgment. Excluded are the auxiliary or "off-engine" components which are usually the responsibility of the shipbuilder.

The engine builder and licensee recommended practices for medium speed engines appear in Table 3-1, pages 3-27 through 3- 43 while the recommended practices for slow speed engines appear in Table 3-2, pages 3- 46 through 3- 62 .

3.1 Slow Speed versus Medium Speed Considerations

Many of the engine builders which were interviewed manufacture medium speed four cycle engines as well as the larger, slow speed two cycle units. This provided a reasonably balanced view regarding the application of performance and condition monitoring equipment to both engine types.

As previously pointed out, the majority of these new performance and condition monitoring techniques have been specifically developed for the large bore, slow speed, two stroke engines. During the survey, it became evident that many of the monitoring techniques routinely employed with these slow speed diesels were not simply transferable "carte blanche" to the medium speed units. The process dynamics of these four stroke engines proved to be significantly faster than their two stroke counterparts. Individual anomalies were also more likely to exhibit themselves on a system level rather than on a component level.

It is imperative that the numerous operational, physical

and thermodynamic characteristics of the medium speed engine be evaluated properly in order to intelligently apply these new performance and condition monitoring techniques. Some of these considerations are outlined and discussed below.

3.1.1 Performance Monitoring Differences

Much of the performance monitoring for the two stroke slow speed engines has traditionally centered around the combustion process. Conventional pressure/volume and pressure/time combustion characteristics have, in the past, proven to be reasonable indicators of engine performance. Newly developed acquisition and analytical techniques have not displaced these methods, but instead have enhanced the ease, repeatability and accuracy of these measurements.

Slow speed two stroke engines are sensitive to variations in both maxiumum pressures and the differential pressures between the maximum firing pressures and the compression pressures. A timing error of only one degree may reduce these differential pressures to one-half of their original values. In cases such as these, the corresponding penalties in fuel consumption range up to five percent. Therefore, the development of these modern diagnostic tools seems justified. Additionally, this technology appears to represent a natural, evolutionary outgrowth of the traditional cylinder combustion monitoring practices.

The situation is not as clear with the medium speed four stroke engines. Acquisition of complex cylinder combustion parameters on these engines has been, in the past, virtually impossible. The four stroke thermodynamic process is simply too fast to enable one to obtain practical indicator or draw diagrams. Until now, the sheer rapidity of the four stroke combustion cycle dynamics has limited the available information to peak combustion pressures.

Experience has proven that the conventional diagnostic parameters such as peak firing pressures and exhaust temperatures are less than reliable. But there are also difficulties with the new techniques. Significant problems such as pressure column phase-shifts and signal oscillations due to medium speed indicator cock connections must be resolved. Not withstanding the above, there appears to be a significant potential for performance enhancement in these areas due to the prior lack of diagnostic information and the large number of cylinders associated with four stroke propulsion plants.

Additionally, even though medium speed engines are at times more tolerant of slight variations in compression or firing pressures, they are much more sensitive to air/gas path disturbances than are slow speed engines. Modern medium speed four stroke engine commonly experience high thermal

loading and, in fact, over the past ten to fifteen years, have more than doubled their specific cylinder outputs. Of course, many design factors and improvements have contributed to this increase but one major factor that stands out is the considerable increase in the RPM, throughput, and overall efficiency of the present day turbocharging systems.

Based on the available information, it appears that more accurate and thorough combustion monitoring can be coupled with more diligent charge air and exhaust monitoring. This should provide the potential for improving, or at least effectively maintaining, the current level of performance of today's medium speed engines while in service.

3.1.2 Component Condition Monitoring Differences

The major difference in the component monitoring of medium speed engines versus slow speed engines is one of emphasis, not one of philosophy. As discussed earlier, one of the basic tenets of a condition based maintenance system is that the investigation of engine failure modes is a must for any intelligent application of condition monitoring.

One major classification society has compiled a data bank on slow and medium speed main propulsion diesel engine failures during the period 1970 through 1980. This study concerned itself only with reported failures, so the data are not all inclusive. Many failures that were dealt with under normal circumstances by the crew, of course, went unreported. Examining this data in a broad perspective illustrates the differences between medium speed and slow speed component condition monitoring.

Generally, the majority of failures in the four stroke trunk type engines were concentrated around the main bearings, turbochargers, crank pin bearings and valves. Whereas the vast majority of slow speed engine component failures involved crosshead bearings, cylinder liners, turbochargers and pistons. There are a variety of new and existing technologies available to monitor all of these components, some effective, some less so. One must first determine which components are most likely to fail and which failures can be tolerated. This should be undertaken prior to expending substantial resources on condition monitoring "black boxes". A good deal of time and money can be squandered on either ineffective or unnecessary monitoring equipment when beginning a maintenance program.

3.2 Recommended Practices

All of the medium speed engine manufacturers surveyed produce trunk piston, four stroke engines which are typically applied

to marine propulsion systems today. The low speed engine manufacturers and their licensees who were surveyed all produce crosshead type, two stroke engines. This type of engine is representative of the engines which will be built under license or other manufacturing agreement in the U.S.A. The following sections and Tables 3-1 and 3-2, pages 3-27 through 3-62 reflect the performance and condition monitoring diagnostic recommendations of these engine builders.

3.2.1 Cylinder Combustion Processes

All five of the slow speed engine builders admitted that conventional combustion monitoring techniques, (i.e. indicator and draw diagrams) have their limitations. But all were not in agreement as to the appropriate replacement technology. There was even a significant disagreement concerning the value of obtaining mean indicated cylinder pressures. Four of the slow speed manufacturers felt that these pressures were of significant diagnostic value while the remaining engine builder felt that these measurements were unnecessary. This single manufacturer felt that sufficient diagnostic information could be obtained from other thermodynamic combustion parameters.

Regarding the medium speed engine builders, the fact of the matter is that, in the past, they have traditionally been unable to utilize MIP's, "Indicator" and "Draw" diagrams as diagnostic tools except on the test bed. Most of these manufacturers today feel wary of the new techniques. They basically question the long-term reliability and durability of these new systems.

Three of the four medium speed engine manufacturers felt that the calculation of cylinder mean indicated pressures was unnecessary. The fourth engine builder felt that these new engine diagnostics could prove to be a valuable tool for the operating engineer.

The monitoring of maximum firing pressures and cylinder compression pressures was judged by all two stroke and four stroke engine builders to be a valuable diagnostic tool. It was specifically suggested that the differential pressures between P_{comp} and P_{max} be observed. These values provide a reasonable snapshot of individual cylinder timing and fuel consumption.

Generally, deviations in either P_{max} or P_{comp} greater than 2.0 $kp.cm^2$ for the slow speed engines and 5.0 bar for the medium speed engines from their mean values should be investigated and corrected. However, it should be noted that on constant pressure charged slow speed engines normal deviations of this magnitude can occur due to the natural consequences of gas vibration within the receivers.

Three of the five two stroke manufacturers felt that additional analytical information could be obtained by monitoring individual cylinder expansion pressures. Consistently high values may indicate a certain amount of afterburning during the combustion process. The remaining two engine builders felt that this information was either unnecessary or unreliable. It should be noted that although the preceding statement regarding afterburning may be true, the inverse is not necessarily valid. That is, if no excessive expansion pressures are observed, it is not necessarily true that there are no fuel problems!

A leading European classification society has conducted numerous tests on known "problem fuels." They have tried unsuccessfully to uncover common physical or chemical characteristics in order to easily identify these deleterious fuels. During these tests, surprising combustion characteristics have appeared, (or rather not appeared)! Figure 3-1 depicts cylinder pressure diagram data for both the "problem" fuel and known diesel fuels. As can be seen, the differences in pressure deviations are insignificant.

As to the acquisition of combustion pressures, three of the five slow speed engine builders preferred uncooled piezoelectric, combustion pressure sensors. One licensee had dealt with the forced air cooled type of sensor primarily, while the remaining engine builder felt that either pressure transducers or manually obtained indicator card readings were appropriate as long as the data was systematically fed into an overall maintenance scheme.

As to the medium speed manufacturers interviewed, one preferred water cooled sensors while one other would tolerate an uncooled transducer.

Four of the five slow speed manufacturers recommended that a single combustion pressure sensor be supplied. This transducer would be moved from cylinder to cylinder as required. The remaining manufacturer, which incidentally provides its own integrated system, normally supplies an individual combustion sensor for each cylinder with permanently installed cabling and charge amplifiers.

The four stroke engine builders generally agreed that permanently mounted sensors were high cost items and presented long-term durability problems.

There are advantages and disadvantages to each approach. The single sensor technique reduced system error through transducer commonality and it is less expensive. The multiple sensor approach is much more convenient but there are risks of plugged sensing tubes, long-term thermal stresses and greater expense.

Figures 3-2, 3-3 and 3-4 depict and describe three typical combustion pressure sensors.

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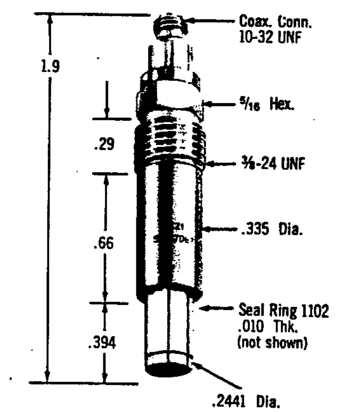
Figures 3-2, 3-3 and 3-4 depict and describe three typical combustion pressure sensors.

FIGURE 3-2

TYPICAL CYLINDER COMBUSTION PRESSURE SENSOR I
(REFERENCE 4)

High Impedance.
The ultimate in engine research transducer. Incorporates patent polystable quartz element. Operation to 350°C without water cooling and ground isolation. Withstands intermittent flash temperatures up to 2,500°C.

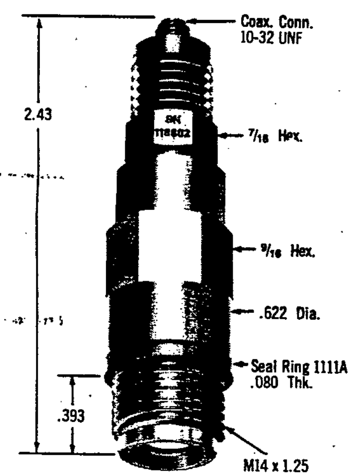


SPECIFICATIONS		
Measuring range	psi	0 to 3,500
Calibrated partial ranges	%	10 & 1
Maximum pressure	psi	5,000
Sensitivity (nom.)	pC/psi	−0.95
Resonant frequency (nom.)	kHz	60
Frequency response ±1%	kHz	6
Rise time (10 to 90%)	μs	6
Linearity & hysteresis	%FS	<±1.0 & <0.5
Acceleration sensitivity	psi/*g*	0.05
Shock & vibration	*g*	<2,000 max.
Temperature sensitivity shift	%/°C	<0.01
Operating temperature range	°C	−80 to 350
Insulation resistance: @ 20°C	Ω	$>10^{13}$
@ 350°C	Ω	$>10^{10}$
Ground isolation	Ω	$>10^{8}$
Weight	g	10

FIGURE 3-3

TYPICAL CYLINDER COMBUSTION PRESSURE SENSOR II
(REFERENCE 4)

High Impedance.
Rugged design, ceramic heat shield for universal applications on internal combustion engines, rocket engines, and explosion chambers. Works reliably under temperatures up to 350°C and withstands intermittent flash temperatures of up to 2,500°C.

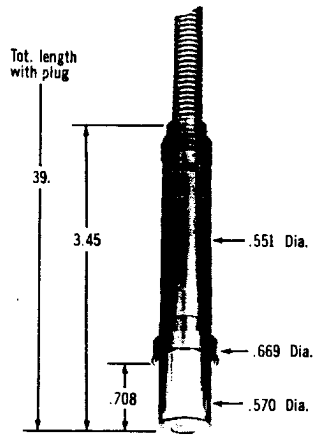


SPECIFICATIONS		
Measuring range	psi	0 to 3,600
Calibrated partial ranges	%	10 & 1
Maximum pressure	psi	5,000
Sensitivity (nom.)	pC/psi	−3.8
Resonant frequency (nom.)	kHz	>40
Frequency response ±1%	kHz	4
Rise time (10 to 90%)	μs	8
Linearity & hysteresis	%FS	<±1.0 & <0.5
Acceleration sensitivity	psi/*g*	0.08
Shock	*g*	2,000 max.
Temperature sensitivity shift	%/°C	<0.01
Operating temperature range	°C	−196 to 350
Insulation resistance: @ 20°C	Ω	$>10^{13}$
@ 350°C	Ω	$>10^{10}$
Weight	g	27

FIGURE 3-4

TYPICAL CYLINDER COMBUSTION PRESSURE SENSOR III
(REFERENCE 4)

High Impedance. Designed for measuring cylinder pressures of large shipboard diesel engines. Rugged construction. Can be mounted in cylinder head without additional water cooling. Features ground isolated element. Minimum operating life of 8,000 hours.



SPECIFICATIONS		
Measuring range	psi	0 to 2,900
Calibrated partial range	%	10
Maximum pressure	psi	4,300
Sensitivity (nom.)	pC/psi	−2.4
Resonant frequency (nom.)	kHz	60
Linearity & hysteresis	%FS	≤ ±1 & ≤ 1
Acceleration sensitivity	psi/*g*	≤ 0.08
Shock & vibration	*g*	≤ 5,000 max.
Temperature sensitivity shift	%/°C	±0.01
Operating temperature range		
(diaphragm to mounting flange)	°C	−50 to 350
(diaphragm to cable section)	°C	−50 to 200
Insulation resistance	Ω	$\geq 10^{13}$
Ground isolation	Ω	$\geq 10^{7}$
Working life	h	8,000
Capacitance	pF	110
Connector	Type	LEMO FEO .550
Weight	g	130

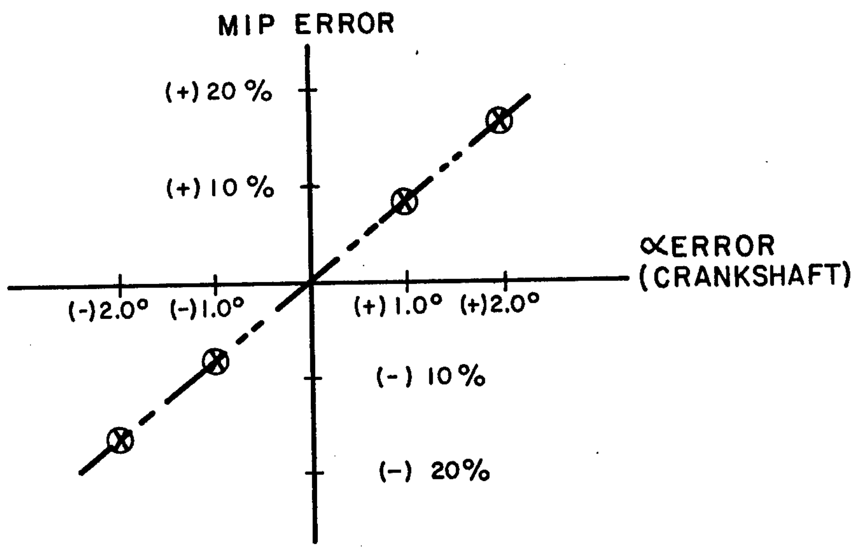
One of the most difficult parameters to accurately obtain and analyze is piston position during the combustion cycle. All of the engine manufacturers agreed that the major difficulty in dynamically determining this value entails compensating for the crankshaft torsional offset at different power levels. In a large bore, two stroke, six cylinder engine, the crankshaft twist from the first to the last cylinder may be in excess of one degree at MCR. This "twist" can result in an MIP error of eight to ten percent. Figure 3-5 illustrates a plot of crankshaft angle error versus MIP error.

The importance of this is obvious when one realizes that a substantial amount of funds may have been expended to achieve the same overall accuracy as a standard MAIHAK, manually plotted, MIP indicator diagram.

There was a substantial divergence of opinion regarding the acquisition and processing of piston position and crankshaft speed. Two slow speed and one medium speed manufacturer utilized rotary encoders mounted on the crankshaft to obtain both piston position and engine speed. A third manufacturer utilized a magnetic proximity probe with ferrous pins mounted on the flywheel. The fourth engine builder also utilized a proximity probe for engine speed but felt that this was insufficiently accurate for the determination of piston position. The remaining manufacturer felt that either a tachometer/generator or a proximity probe was sufficient

FIGURE 3-5

CRANKSHAFT ANGLE ERROR INFLUENCE ON MIP
(REFERENCE 5)



for engine speed determination and if the MIP could not be determined due to piston location inaccuracies, the horsepower or kilowatt output of the engine could be just as reliably calculated from the fuel rack position.

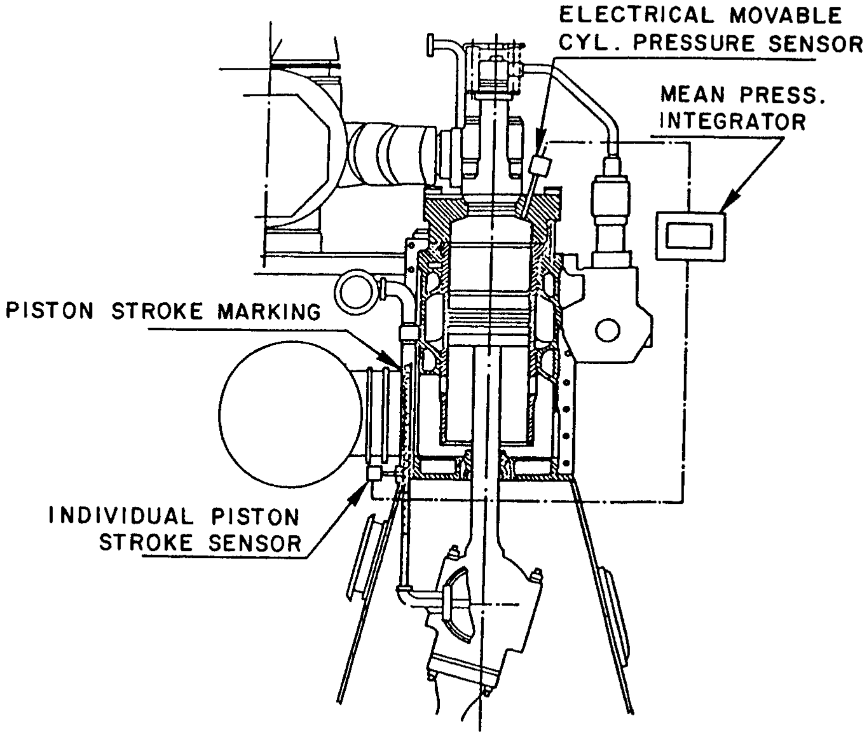
This disagreement among manufacturers centered not on whether this MIP error could be significant but on how best to compensate for it. Most manufacturers felt that it could be factored into the computational process. One slow speed engine builder was less certain of this. This manufacturer recommended individual inductive piston stroke sensors mounted on each cylinder. Figure 3-6 provides a layout of this system.

3.2.2 Fuel Injection Processes

Both the two stroke and four stroke fuel injection dynamic pressures and their associated timing functions can now be monitored directly by newly developed transducers and micro-processing equipment. Piezoelectric/high pressure sensors provide analytical information on the injection process never before available. In the past much of the diagnostic information regarding the fuel system has been derived from secondary parameters such as combustion pressure diagrams.

FIGURE 3-6

INDIVIDUAL PISTON STROKE SENSORS
(REFERENCE 6)

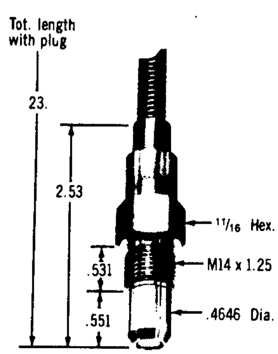


The sensors themselves must withstand extremely high transient pressures on the order of 1500 bar (21,000 psi). Due to these high pressures, some of the manufacturers are reluctant to physically intervene in the fuel delivery process. Acceptance of these monitoring techniques has been slow due to the preceding apprehensions, questions regarding the long-term durability of the sensors, and their high cost. Details of a typical fuel pressure sensor are presented in Figure 3-7.

FIGURE 3-7

TYPICAL FUEL PRESSURE SENSOR
(REFERENCE 4)

High Impedance. Designed for fuel injection systems of large shipboard diesels. Measures fuel injection pressure up to 21,000 psi. Features ground isolated signal. Minimum operating life of 8,000 hours.



SPECIFICATIONS		
Measuring range	psi	0 to 21,000
Calibrated partial range	%	10
Maximum pressure	psi	29,000
Sensitivity (nom.)	pC/psi	−0.2
Resonant frequency	kHz	>100
Rise time (10 to 90%)	μs	2.5
Linearity	%FS	≤ ±1
Acceleration sensitivity	psi/g	<0.3
Shock	g	1,000 max.
Temperature sensitivity shift	%/°C	±0.01
Operating temperature range	°C	−50 to 200
Insulation resistance	Ω	$>10^{14}$
Ground isolation	Ω	$>10^{7}$
Working life @ 15,000 psi	h	8,000
Capacitance	pF	63
Connector	Type	LEMO FEO .550
Weight	g	120

Four of the five slow speed and all of the medium speed engine manufacturers did not recommend fuel oil injection pressure monitoring. They felt that sufficient diagnostic information could be obtained from the trained observation of the more conventional combustion pressure/time parameters.

One European manufacturer recommended the installation of multiple, uncooled, piezoelectric fuel pressure sensors. This engine builder felt that the maximum injection pressures, angles and durations of valve openings provide important and useful diagnostic information. The system currently offered by this manufacturer includes permanently mounted individual injection sensors for each cylinder.

One medium speed engine builder felt that strain gauge type sensors were more suitable for this process. These would record the timing functions of the fuel delivery cycle but not the absolute pressure values.

A substantial amount of investigation and experimentation has been conducted by various engine manufacturers regarding the monitoring of thermal loads within the combustion chamber. Numerous attempts have been made to correlate these thermal excursions with fuel quality, injection patterns and degraded fuel nozzles. As an outgrowth of these efforts, many engine builders have experimented with imbedded chromel/alumel type thermocouples in the cylinder covers to monitor thermal loading. The consensus among the engine manufacturers seems to indicate that these values are too difficult to normalize and are of limited value as a practical diagnostic tool, other than on the test bed under closely controlled conditions.

Table 3-1, Fuel Oil Injection Processes, page 3-28, reflects the opinions of the medium speed engine builders. Table 3-2, page 3-47, presents the recommendations of the slow speed engine manufacturers regarding this subject.

3.2.3 Air/Gas Path Processes

Monitoring the air/gas path can provide useful information regarding the overall adequacy of the air/fuel combustion process. Although it should be noted that difficulties arise in utilizing these temperatures and pressures as effective diagnostic tools due to the following three factors:

* Instrument accuracy, repeatability and long-term drift.

* "Consequential" causes and effects.

* Uncertain correlation between the actual process dynamics and the monitored variables.

The first of these difficulties, instrument accuracy and repeatability, relates to the requirement to measure high absolute exhaust temperatures ($400^{o}C/750^{o}F$) and extremely low differential air pressures (0.002 bar). The best accuracy of "conventional" instruments is usually about $\pm$ 2%. This, of course, is when the equipment is new, properly calibrated, and continuously maintained. In practice, the normal accuracies are more on the order of about $\pm$ 5%. This translates to a potential error of approximately $40^{o}C$ between the exhaust temperature measurements of two different cylinders.

The second problem area concerns the diagnostic conclusions that can be drawn from the measured parameters. Scavenging air and exhaust anomalies are seldom caused by single defects. Conversely, performance deviations usually do not manifest themselves in such a manner as to be easily attributable to single, identifiable causes. This is due to the fact that the air and gas system thermodynamics are closely interwoven and interact with each other. Effective trouble-shooting requires a good deal of analytical investigation and plenty of old-fashioned detective ingenuity.

Lastly, there must be sufficient confidence in the validity of the monitoring/diagnostic process itself. For example, one common practice is the monitoring of exhaust gas temperatures at each cylinder outlet. This is normally considered a reasonable indication of the thermal load for that cylinder. Various tests have been conducted on medium speed engines attempting to validate these assumptions.

In one investigation, good correlation was obtained between the valve face temperature, (which represents the actual value needed to predict thermal load and the burning of the valves), and the valve seat temperature. This correlation was based on data from three different engines and took the mathematical form of:

$$T_{ref} = C_5 + C_6 \left(MIP^{0.35} \cdot T_s^{0.45} \cdot P_s^{-0.45} \cdot \Delta te^{0.5} \right)$$

(REFERENCE 7)

Where:

T_{ref}	=	Exhaust Valve Seat Temperature reference value.
C_5 & C_6	=	Constants
MIP	=	Mean Indicated Pressure
T_s	=	Abs. temperature of charging air before cylinder.
P_s	=	Pressure of charging air before cylinder.
Δte	=	Exhaust temperature (-) Air temperature before charger inlet.

Using the valve seat temperature as the thermal load parameter, the individual cylinder exhaust temperatures were monitored on a vessel with two medium speed, four stroke engines. The results indicated that the thermal loads between cylinders varied as much as 15%, but the differences between exhaust temperatures were negligible

A good number of the engine builders and research organizations that were surveyed voiced many of these same concerns. These practical difficulties will be further addressed in Sections 4.0, 6.0, and 7.0.

The current recommended practices of the surveyed engine builders concerning these functions are contained in Table 3-1, Air and Gas Path Processes, pages 3-29 through 3-32 for medium speed and Table 3-2, pages 3-48 through 3-51 for slow speed engine builders.

3.2.4 Cylinder Components (Rings, Grooves, and Liners)

Many of the two stroke slow speed cylinder components can be visually inspected during the in-port vessel turn-around time. This basic fact tended to influence each engine builder when presenting various levels of recommended cylinder component condition monitoring. The following summarizes the current views of each manufacturer regarding the monitoring of piston rings, grooves, and liners.

Two of the five slow speed engine builders and one of the medium speed manufacturers recommended piston ring condition monitoring. One builder markets its own system which consists of a single high speed magnetic pick-up mounted in each cylinder liner and a special piston ring fitted with a non-magnetic, v-shaped brass wear band. This arrangement allows monitoring not only of the piston physical condition such as sticking, breaking or ring collapse but also the amount of wear on the upper ring.

The other slow speed engine builder and one medium speed engine builder recommended a less sophisticated magnetic proximity probe which would indicate the failure mechanisms within the ring groove interface but basically would not indicate wear. The three remaining slow speed engine builders felt that visual inspection of the rings was sufficient. One manufacturer in particular felt that the inspection of rings, grooves, and liners was so easily accomplished with his engine layout that this monitoring equipment was superfluous.

All medium speed and slow speed engine builders and licensees agreed that the most appropriate way to examine and monitor piston grooves was by visual inspection. No sensors have been developed or were contemplated to supplement this visual inspection.

There was a substantial amount of disagreement concerning the value of cylinder liner temperature monitoring whether it be for blow-by, scuffing or wear. Three slow speed manufacturers felt that the monitoring of upper cylinder liner temperature was unnecessary. One licensee felt that the placement of four chromel/nickel thermocouples between the first and second piston ring was desirable. The remaining two stroke engine builder felt that if upper cylinder temperature monitoring was desired by the vessel operator, its main value would not necessarily be diagnostic in nature but it would be primarily used as an alarm function.

Four of the five slow speed engine builders felt that temperature monitoring of the lower liners was unnecessary. One manufacturer again felt that; as an option, if the vessel operator installed this monitoring; its prime value would be as an alarm function and not as a diagnostic tool.

As for liner scuffing, there were three distinct approaches. Two slow speed manufacturers recommended a single chromel/nickel thermocouple imbedded in the lower liner. Experience with this engine design had proven that if scuffing were to be encountered it would be in the lower part of the liner on the exhaust side.

Another two stroke manufacturer has developed its own unique monitoring system for liner scuffing. This engine builder recommended four coaxial, chromel/alumel high response, (40 uv/^{o}C), thermocouples mounted midway in the liner adjacent to the cylinder lubrication inlets. This installation is unique in that it seeks to monitor excessive temperature gradients across the surface of the liner and not liner temperature per sé. This manufacturer felt that these measurements are highly accurate in predicting abnormal cylinder liner wear and damage. Figures 3-8 and 3-9 illustrate typical locations, installation methods and electrical characteristics of these sensors.

This scuffing system is also offered with an additional option. Individual cylinder lube oil flows can be increased or decreased depending upon the severity of the liner surface temperature gradients experienced. Not only does this system automatically increase cylinder lube oil during periods of micro-seizures it also reduces the normal lube oil consumption during quiescent periods. The manufacturer claims that the overall cylinder lube oil consumption is approximately cut in half. The remaining two slow speed engine builder/licensees felt that the monitoring of scuffing was unnecessary.

All four of the medium speed engine manufacturers felt that liner temperature monitoring was presently impractical.

As to the monitoring of cylinder liner wear, all engine builders agreed that the preferable solution to this was

FIGURE 3-8

TYPICAL SCUFFING SENSOR LOCATION IN CYLINDER LINER
(REFERENCE 6)

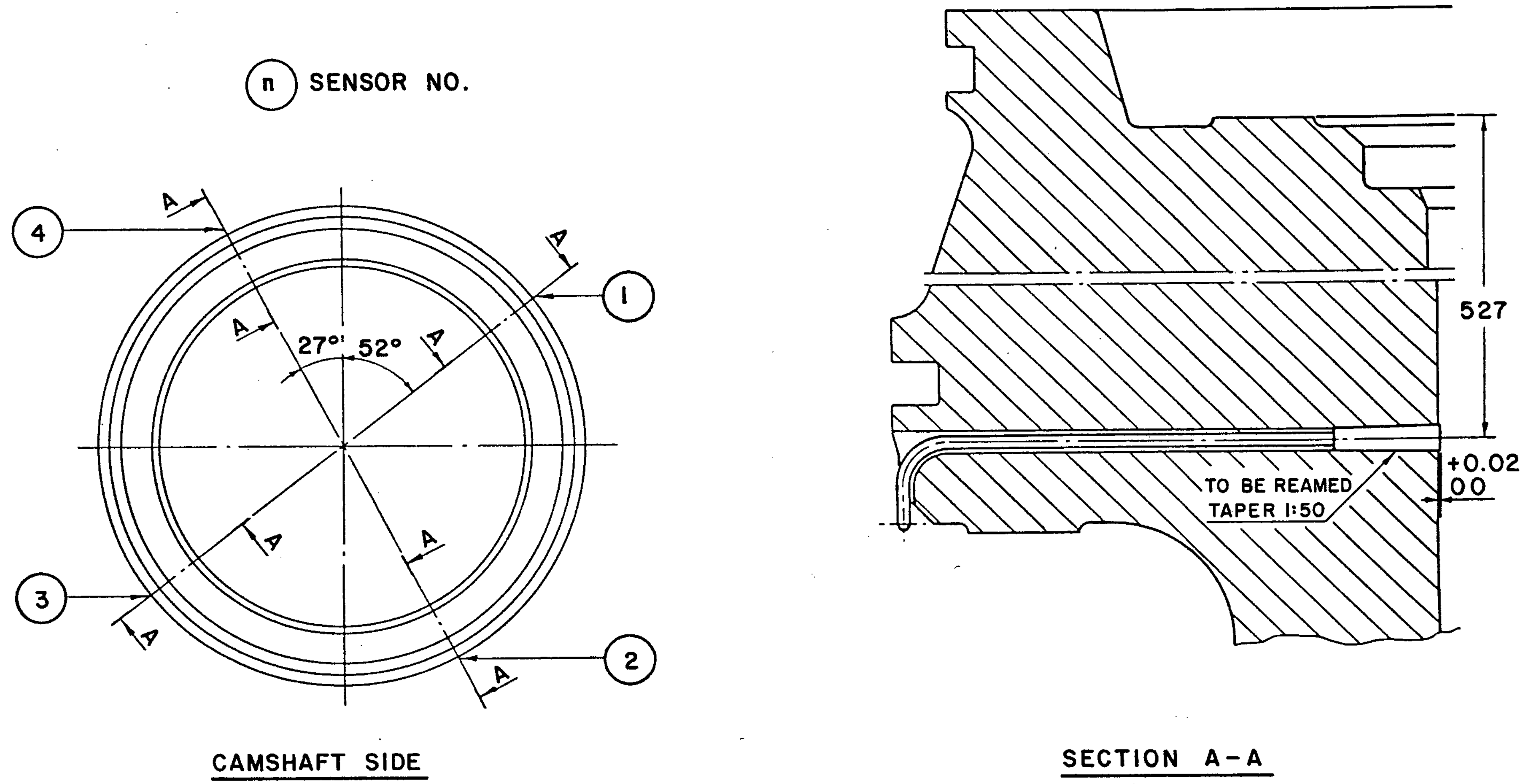
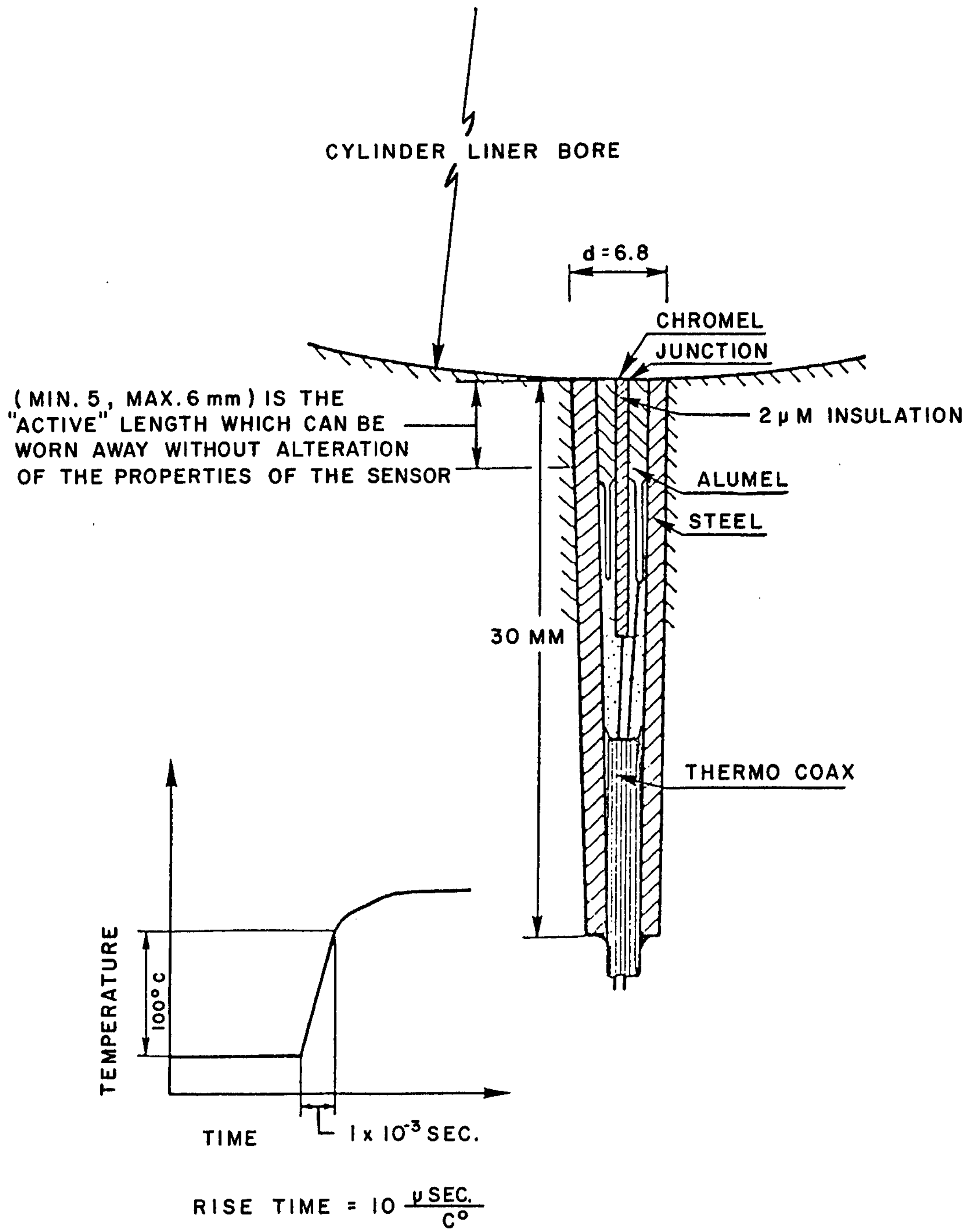


FIGURE 3-9

SURFACE THERMOELEMENT FOR CYLINDER LINER
(REFERENCE 6)



the visual inspection of each liner either during engine overhaul or during the normal in-port maintenance evolution. They felt that this was a much more reliable solution to liner monitoring than the installation of the more sophisticated imbedded thin-film resistor type of wear sensors.

Tables 3-1 and 3-2, Cylinder Components, pages 3-33 and 3-34 and 3-52 and 3-53, respectively illustrate the condition monitoring practices of the medium speed and the slow speed engine builders in these areas.

3.2.5 Air/Gas Path Components

As mentioned earlier in the discussion of performance analysis of the air/gas path process, numerous pressures and temperatures must be accurately monitored. This is not only to insure the proper assessment of the overall air/fuel process but also to adequately monitor the individual components.

The following sub-systems are normally monitored from a condition standpoint.

* Scavenging Air Inlet Filters.
* Charge Air Coolers.
* Turbochargers.
* Exhaust Valves/Scavenging Ports.

Scavenging air inlet filters are usually monitored by observing the differential pressures across the inlets. U-tube manometers or differential pressure transducers are normally utilized. Maintenance actions are recommended to be taken when the pressure losses are 50% higher than those measured on the test bed.

The charge air coolers and intercoolers are monitored by tracking various pressure and temperature trend deviations. These parameters are outlined in Tables 3-1 and 3-2, Air Gas Path Processes, pages 3-29 through 3-32 and 3-48 through 3-51 . It should be noted that there is one particularly useful measurement utilized in assessing the overall condition of the charge air coolers. This is the differential temperature between the air out of the coolers and the salt water into the coolers. Deviations above 25^{o}C indicate a requirement for corrective action.

Turbocharger condition is difficult to analyze and diagnose properly due to the interaction of numerous physical and thermodynamic characteristics.

The plotting of turbine speed versus scavenging pressure provides an approximate overall view of the general condition of both the air and gas sides of the turbochargers. Basically, if the rpm/pressure ratio is decreasing, a fouled turbine side is indicated. If this ratio is rising, then the fouling of filters, coolers or compressors is likely. For a more detailed diagnostic analysis, measurements such as those described in Tables 3-1 and 3-2, Air/Gas Path Processes, pages 3-29 through 3-32 and 3-48 through 3-51 are recommended.

Regarding turbocharger vibration, no slow speed engine builder recommended this function although three of the four medium speed manufacturers felt this condition monitoring was useful.

Exhaust valve condition is also difficult to assess due to the variety of technical reasons already cited in Section 3.2.2, page 3-9 . The single slow speed engine builder who utilizes a two stroke, valved design, recommended more intensive monitoring of the air/gas path process, increased integration of the newly developed combustion monitoring techniques into the overall maintenance scheme and frequent visual inspection of the individual valves and valve gear components. These practices are outlined in Table 3-2, Air/Gas Path Components (Exhaust Valves) page 3-54 through 3-55.

It should be noted that the above manufacturer is introducing a new rotating valve design which will increase the likelihood of valve seat burn and leak detection over the traditional stationary valve and thermocouple arrangement. If the valve rim is damaged on its periphery, this will be revealed by an elevated transient exhaust temperature rise, as this spot rotates past the fixed thermocouple.

Medium speed engine builders were also concerned with valves, valve seats, and valve gear component conditions. As with their slow speed counterpart, a variety of measures were recommended. These also included more systematic and intensive monitoring of the gas path processes, coupled with increased attention paid to cylinder combustion characteristics.

One fortunate aspect regarding valve seat erosion and face burning is the somewhat mitigating factor that although individual valve casualties are aggravating and expensive, they are not normally of sufficient magnitude to immobilize the vessel. The current recommended practices of the medium speed engine builders surveyed regarding this item are contained in Table 3-1, Air/Gas Path Components, page 3-35 and 3-36.

3.2.6 Drive Train Bearing Components

Adequate drive train bearing condition monitoring has proven to be an elusive goal in the diesel engine manufacturing and operating community. Engine builders have pursued a

variety of technological approaches in attempting to predict potential bearing failures. The following techniques have been implemented on both two and four stroke engines with varying degrees of success.

* Oil Mist Concentration Monitoring
* Return Oil Flow Temp. RTD's
* Bearing Shell Metal Temp. RTD's
* Bearing Shell Metal Temp. Thermistors (wireless)
* Oil Temp. Melt Capsules
* Crankshaft Deflection Analysis
* Vertical Displacement Analysis
* Lube Oil Analysis
* Accoustical Signal Analysis
* Torsional Vibration Analysis

Oil mist opacity monitoring is normally supplied by all of the slow and medium speed engine builders, although there are times when this system has its limitations.

Three of the five slow speed engine builders generally recommended that additional monitoring be provided to supplement the oil mist detection equipment. These manufacturers recommended return oil flow temperature RTD's coupled with regular crank web deflection readings.

All of the medium speed engine manufacturers felt that additional monitoring was also desirable, but then disagreed on the preferable techniques. Two engine builders preferred monitoring the bearing shell temperatures directly; one felt that return oil flow RTD monitoring was sufficient and one had experimented with torsional vibration analysis. These practices are shown in Tables 3-1 and 3-2, Drive Train Bearing Components, pages 3-37 through 3-38, and pages 3-56 through 3-57 , respectively.

3.3 Data Processing, Utilization and Display

Two of the seven engine builders were significantly involved with the utilization and processing of acquired data. One manufacturer was involved primarily from a hardware standpoint and the other from a software or management perspective.

The processing and display functions of the first manufacturer include digital processing and transmission with multiple digital displays and off-line printing. Data normalization is performed internally with external high/low limit alarms. Trend processing is handled by regression analysis in one week intervals. This data is permanently stored in the CPU and on cassette tape. Self-testing and internal diagnostics for the electronic subsystems are also provided.

The second engine builder was more concerned with the overall management of the maintenance process. Their thoughts centered around the dissemination of maintenance guidance to the operator with off-line processing and analysis at the engine manufacturers facility. An illustration of a typical data acquisition form (partial) is shown in Figure 3-10.

The processing of the gathered data is then undertaken at the engine builder's facility and the following information is supplied to the shipowners:

* Complete maintenance schedule with activities due and overdue.

* Performance assessment.

* Detailed wear rates.

Typical representations of this data are shown in Figures 3-11, 3-12 and 3-13.

3.4 Use of Tables

The following tables provide a summary of both the medium speed and slow speed manufacturers' recommendations relative to engine parameters to be monitored and the methods for monitoring and measurement. Table 3-1 addresses the medium speed manufacturers and Table 3-2 presents the recommendations of the slow speed manufacturers. As in the previous tables the information is presented by subsystem with individual subsystem parameters identified. For each manufacturer the number and types of sensors recommended to monitor the specific parameter are identified. Also provided is the recommendation by the engine manufacturer as to the type of display associated with each parameter. These, for example, would include local and remote gauges, CRT's, printers, digital displays, etc. Where manufacturers did not recommend the application of monitoring or measuring devices to specific parameters but suggested visual inspection and/or manual measurement these areas are so identified.

Figures 3-14 and 3-15 provide a listing of the abbreviations and symbols used in Tables 3-1 and 3-2.

FIGURE 3-10

TYPICAL FOUR-STROKE DATA ACQUISITION FORM (PARTIAL) (REFERENCE 8)

OPERATING DATA LOG FOR FOUR STROKE ENGINES

Plant/Ship	Engine Type

Engine	Maker	Engine No.	Total Operating Hours	Measurements Year	Month	Day	Hour	Minute	Set No.
engine									

	Speed 1/min	Effective Output (Torque Measurements)	Engine Room °C Temperature	% Relative Air Humidity	Control Air Pressure	Governor Fuel Admission Reading Scale Graduation	% Speed Droop Setting	Control Console Fuel Admission Reading Scale Graduation	Exhaust Gas Picture Code 1	Selection Code 1 0	Cylinder Numbering Code 2
11					.	.	.	.			

Cylinder Number			1	2	3	4	5	6	7	8	9
Fuel Pump Setting Scale Graduation	Cyl. Bank A	12									
	Cyl. Bank B	13									
Compression Pressure bar	Cyl. Bank A	14									
	Cyl. Bank B	15									
Firing Pressure bar	Cyl. Bank A	16									
	Cyl. Bank B	17									
Exhaust Temperature °C	Cyl. Bank A	18									
	Cyl. Bank B	19									
Coding Water Temperature after Cylinders °C	Cyl. Bank A	20									
	Cyl. Bank B	21									

	Cooling Water Pressure		°C Cooling Water Temperature				Lubricating Oil Pressure							Lube Oil Temperature				
	Engine	Injectors	Engine		Injectors		Main or Automatic Filter		Indicator Filter		Engine	Rocker Arm	Thrust Bearing	Engine		Thrust Bearing	Crankcase Pressure	Oil Mist Detector
	BEFORE	BEFORE	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	BEFORE	BEFORE	BEFORE	AFTER	AFTER		
22	.	.					.	.	.	.	.	.	.				.	

Waste Heat Boiler	Exhaust Temperature, °C	
	Before	After
23		

Code 1

1 1 Invisible, scarcely visible
1 2 Visible, still satisfactory
1 3 More visible, but still transparent, highly sooty
1 4 Sooty, (opaque) - black

Code 2

2 1 Continued from coupling and
2 2 Counted from free and

Code 3

3 1 Cyl. Bank A
3 2 Cyl. Bank B

Turbochargers	Turbocharger Numbering		Charge Air Pressure	Exhaust Back Pressure Before Turbine Mode of Numbering as per Test Run Report				After Turbine	Exhaust Temperature °C Before Turbine Mode of Numbering as per Test Run Report				°C After Turbine
	Code 2	Code 3		Duct 1	Duct 2	Duct 3	Duct 4		Duct 1	Duct 2	Duct 3	Duct 4	
24			.	.	.	.	.	.					
25			.	.	.	.	.	.					

	Speed 1/min	Cooling Water Temp. After °C	Lubricating Oil Pressure	Lubricating Oil °C Outlet Temp.	Lubricating Oil Sump Temp. Turbine	Lubricating Oil Sump Temp. Compr.	Air Inlet on Compr Negative Pressure	°C Temp.
26			.				.	
27			.				.	

Intercooler Differential Pressure (Air)	°C Air Temp. Before	°C Air Temp. After	Cooling Water Temperature Before	Cooling Water Temperature After
.				

FIGURE 3-11

TYPICAL MAINTENANCE SCHEDULE
(FOUR-STROKE ENGINES)
(REFERENCE 8)

EVALUATION NO.

LIST OF FEEDBACK MESSAGES

SHIP NAME ENGINE MODEL ENGINE SERIAL NO.

ITEM/MAIN COMPONENT / COMPONENT / ACTIVITY-DESCRIPTION / POSITION / FINDING / AT ACTION TAKEN	AN/BGR	QTY.	LOCATION / TEXT	KL	OPER. HOURS	MK	AR	EXPENSE E	EXPENSE M	EXPENSE MH	BE	IN	LN.NE-SN/DATE /OF
MAIN BEARING / REMOVE/REINSTALL / REPLACE	021B2500	2	NO. 2	K	12480			A	2	6.00	2	A	PORT 0501.99-1/79.4.7/B
	021B2500	3	NO. 1,5,6		13467			B	2	20.00	2	A	PORT 0346.00-1/79.5.8/B
INSPECT BEARING	021B2520	3	NO. 1,5,6,		13467			B	1	1.00			0346.00-2/79.5.8/B
INLET AND EXHAUST VALVES / CHECK VALVE ROTATION	113B0500	ALL			11500			B	1	2.00	1	A	SEA 0.500.00-1/79.10.1/B
	113B0500				12919			A	1	2.50	1	A	SEA 0350/00-1/79.4.30/A
	113B0500	ALL			13982			F	1	1.70	1	A	SEA 0410.00-1/79.5.15/B
	113B0500$	ALL			19520			B	1	2.20	1	A	SEA 0430.00-1/80.3.29/B
INLET VALVE / MEASURE VALVE CLEARANCE	113D01100	ALL $			12470			B	2	0.80	2	A	PORT 0490.00-1/79.4/2/B
READJUST VALVE CLEARANCE	113D1120	3	A-B/C/CYL 3 B-B/F/CYL 1,2		12470			B	1	0.20			0347.00-1/79.4.2/B

AT: AT = EXCHANGED PART; KL: K = RECOGNIZED CLASS RENEWAL: MK = MESS. IDENTIFIER; AR: S = SECONDARY (SUBSEQUENTLY MESSAGE); EXPENSE E: A = ENGINE MANUFACTURER; B = OPERATOR; F = OTHER; EXPENSE M: QUANTITY MEN; EXPENSE MH: QUANTITY MENHOURS; $ = ASSUMED; OF: A = ENGINE MANUFACTURER; B = OPERATOR; BE: 1 = RUNNING, 2 = SHUTDOWN; IN: A = INTENTIONED (SCHEDULED + UNSCHEDULED), 2 = CONDITIONED

FIGURE 3-12

TYPICAL PERFORMANCE ASSESSMENT
(FOUR-STROKE ENGINES)
(REFERENCE 8)

```
SHIP NAME                                                                                    DATE
ENGINE MODEL

==================================================================================================

MCR       16,000 HP,   430.0 1/MIN,   PE  =  17.92 BAR

/

/          ENGINE SERVICE DATA CONTROL
RECORDED AT                                 TOTAL RUN       9416 H

==================================================================================================

/          NAUTICAL DATA
POSITION              8/59 N          18/1W       DEGR/MIN          COURSE            2.0 DEGR
SPEED LOG/GROUND                   14.51/15.37    KN                WIND          NE  3   FORE
MEAN DRAUGHT                          37/ 4       FT/IN             SEA               2   FORE
STERN TRIM                             0/ 2       FT/IN             WATER TEMP       22.0 DEGR
/          ETA                        19/ 5       DAY/H             BAROMETER        1024 MBAR
/        PERFORMANCE
/       OUTPUT - IND-OUTP              M.I.P.      /            EFF-OUTP     M.E.P.   FUEL-CONSUMPT
MEASUREMENT          HP                  BAR       /               HP          BAR    G/BHPH(C VALU)
BY FUEL-RACK      15  722             17.61        /            13  930      15.60    149.1 (143.0)
/
/
PROPELLER PROPULSION                   /  CHECK AGAINST MCR. CURVE AND CONST. VALUE FOR
MEAS. VAL 1/1 LOAD        (0/0)        /  SPEED (0/0) OUTPUT  (1/MIN)  M.E.P. (0/0)
SPEED                     100.0        /   -      -     19.4   410.6   -7.2  107.16
OUTPUT                     87.1        /   -    87.1
M.E.P.                     87.1            PROPELLER TURNS LIGHT, FIELD NO. 1
/        REMARKS

UNAVAILABLE OPERATING DATA
/    TEMPERATURE
/    T      SCAVENGE AIR
/    T         COOLER                 INLET 1   2
/    PRESSURE
/    P      EXHAUST GAS
/    P         TURBINE               OUTLET 1   2
/
/    COMPARISON OF OPERATING DATA, ENGINE MEAN VALUES
OUTPUT FOR CALCULATED VALUE BY FUEL RACK POSITION
NO   MEASURING POINT                          POSITION          M VALUE (C VALUE DIM)        K VALUE

==================================================================================================

101  FIRING PRESSURE                          ENGINE              110(     119   BAR          )0.87
102  COMPRESSION PRESSURE                     ENGINE             76.1(    77.1   BAR          )0.99
103  EXHAUST TEMP. AFTER CYL.                 ENGINE              391(     397   GRDC         )0.93
104  MEAN INDICATED PRESSURE                  ENGINE            17.61(   17.61   BAR          )
```

FIGURE 3-13

TYPICAL WEAR DATA SURVEILLANCE
(FOUR-STROKE ENGINES)
(REFERENCE 8)

SHIP NAME   DATE
ENGINE MODEL   ENGINE SERIAL NO.

WEAR DATA SURVEILLANCE: EVALUATION VA200
REFERENCED OPERATION PERIOD 18200 H

EVALUATION HAS BEEN MADE FOR THE LAST MEASUREMENT TAKEN ON EACH COMPONENT

RING GROOVE MEASUREMENTS

A: PISTON NO.
B: GROOVE NO.
C: 2-STROKE: TYPE OF GROOVE: 1= STANDARD, 2= CHROMIUM-PLATED, ONE SIDE
3= CHROMIUM-PLATED, ON TWO SIDES
D: DATE OF MEASUREMENT
E: TOTAL ENGINE OPERATING HOURS AT TIME OF MEASUREMENT
F: TOTAL OPERATING HOURS OF PISTON AT TIME OF MEASUREMENT
G: OPERATING HOURS SINCE LAST REMACHINING AT TIME OF MEASUREMENT
H: OPERATING HOURS BETWEEN MEASUREMENT AND REFERENCED OPERATION PERIOD
I: REMACHINED TO GROOVE SIZE ... MM
J: LARGEST, ACTUAL GROOVE SIZE MEASURED
K: WEAR RATE, RELATED TO NOMINAL DIMENSION OR REMACHINING, MM/1000 H
L: LIMIT SIZE OF GROOVE REACHED IN APPROX. ... H = REMAINING SERVICE LIFE AS FROM REFERENCED OPERATION PERIOD

LIMIT SIZE OF GROOVE:
1. CRITERION C.1: NOMINAL DIM. OR RING HEIGHT + MAX. PERMISSIBLE CLEARANCE (A CORRESPONDINGLY REVISED NOMINAL SIZE APPLIES TO OVERSIZE RINGS)
2. CRITERION C.2: MAX. PERMISSIBLE, ACTUAL GROOVE SIZE WHEN INSTALLING OVERSIZE RINGS

C.1:	1	10.60 MM	C.2:	1	11.60 MM
	2	10.50 MM		2	11.50 MM
	3	10.40 MM		3	11.40 MM
	4	10.40 MM		4	11.40 MM
	5	16.25 MM		5	17.25 MM

A2/	1	/	/79-10-02/	16421/16421	/	1779/	/10.48/0.012/	8000
A2	2	/	/79-10-02/	16421/16421	/	1779/	/10.38/0.006/	18000
A2	3	/	/79-10-02/	16421/16421	/	1779/	/10.18/0.002/	50000
A2	4	/	/79-10-02/	16421/16421	/	1779/	/10.18/0.002/	50000
A2	5	/	/79-10-02/	16421/16421	/	1779/	/16.12/0.004/	30000

PISTON RING OPERATING HOURS

PISTON-NO/	RING-NO/	TYPE OF R/	RING HAS BEEN IN OPERATION FOR (TILL REFERENCED OPERATION PERIOD)
A2 /	1	/PLASMA /	1779
A2 /	2	/CHROME /	16421
A2 /	3	/BIMETAL /	16421
A2 /	4	/BIMETAL /	16421
A2 /	5	/OILSCR. /	1779

FIGURE 3-14

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 3-1

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
ABS	Absolute	HYGR	Hygrometer
AN	Anemometer	IND	Inductive
BK	Bank	LOG	Engine Room Log
BRG	Bearing	LOC	Local
BLR	Boiler	MAN	Manometer
CALC	Calculated	MEP	Mean Effective Pressure
CLR	Cooler	MNL	Manual
CPI	Combustion Pressure Indicator (Manual)	NA	Not Applicable
CRT	Cathode Ray Tube	NAV	Not Available
CYL	Cylinder	NR	Not Recommended or Required
DSDR	Depth Sounder	PG	Pressure Gage
DIG	Digital	PVG	Pressure Vacuum Gage
ELPU	Electronic Pick-Up	PPT	Piezoelectric Pressure Transducer
ENG	Engine	PT	Pressure Transducer
ER	Engine Room	RE	Rotary Encoder
FM	Flow Meter	REM	Remote
FR	Fuel Rack	REMG	Remote Gage or Indicator
GEN	Generator	RTD	Resistance Temperature Detector
HR	Heat Release		
HTR	Heater		
HRS	Hours		

FIGURE 3-14

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 3-1 CONTINUED

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
SPLG	Speed Log		
SCAV	Scavenging		
SEP	Separator		
SG	Strain Gage		
SHFT	Shaft		
TACH	Tachometer		
TC	Thermocouple		
T/C	Turbocharger		
IPBR	Inductive Probe		
TG	Temperature Gage		
TM	Torque Meter		
VISC	Viscosimeter		
$\triangle$	Differential		
OMM	Oil Mist Monitor		
TGEN	Tachogenerator		
VIBPU	Vibration Pick-Up		
VISI	Visual Inspection		
VIS	Viscosimeter		
WPPT	Water Cooled Piezoelectric Transducer		
VES	Vessel		

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
				SENSOR			SENSOR			SENSOR			SENSOR			
		SYMBOL	DESCRIPTION	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	
1	CYLINDER COMBUSTION PROCESSSES	Pmi/or MIP	MEAN INDICATED PRESSURE (per cylinder)	NR	NR	NR	1/ENG	UPPT (1)	REM DIG	1/CYL	WPPT	CRT (2)	NR	NR	NR	(1) OPTION
2																(2) WITH ALPHA NUMERICS
3		P_{max}	MAXIMUM OR FIRING PRESSURE (per cylinder)	1/ENG	CPI	LOCG	ITEM 1 (3)	CPI/ UPPT	LOCG/ DIG	ITEM 1 (3)	WPPT	CRT (2)	1/ENG	CPI	LOCG	(3) COMMON SENSOR
4		P_{comp}	COMPRESSION PRESSURE (per cylinder)	ITEM 3 (3)	CPI	LOCG	ITEM 1 (3)	CPI/ UPPT	LOCG DIG	ITEM 1 (3)	WPPT	CRT (2)	ITEM 3 (3)	CPI	LOCG	
5		P_{exp}	EXPANSION PRESSURE (per cylinder)	NR	NR	NR	NR	NR	NR	ITEM 1 (3)	WPPT	CRT (2)	NAV	NAV	NAV	
6																
7		$\propto P_{max}$	ANGLE OR TIME OF P_{max} (per cylinder)	NR	NR	NR	1/ENG	RE (1)	DIG	1/ENG	RE	CRT (2)	NAV	NAV	NAV	
8		$\propto P_{comp}$	ANGLE OR TIME OF P_{comp} (per cylinder)	NR	NR	NR	ITEM 7 (3)	RE (1)	LOCG DIG	ITEM 7 (3)	RE	CRT (2)	NAV	NAV	NAV	
9																
10		RPM	SPEED AT ENGINE FLYWHEEL	1/ENG	TGEN	REMG	1/ENG	TGEN/ RE	REMG/ DIG	1/ENG	RE	CRT (2)	1/ENG	TGEN	REMG	
11		T/BHP	TORQUE/BHP AT ENGINE (value, method & location)	1/ENG	FR	LOCG	1/ENG/ SHFT	MEP, IM,FR	DIG/ LOCG	1/ENG/ SHFT	MEP& HR&TM	CRT (2)	1/ENG	FR	LOCG	
12		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/BANK	PG	LOCG	1/BANK	PG	LOCG	1/BANK	PT	CRT (2)	1/BANK	PG	LOCG	

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
13	FUEL OIL INJECTION PROCESSES	POS & % DROOP	FUEL GOVERNOR POSITION AND % SPEED DROOP	1/ENG	VISI	NA	1/ENG	VISI	NA	1/ENG	VISI	NA	1/ENG	VISI	NA	
14		INDEX	FUEL PUMP INDEX (per cylinder)	1/CYL	VISI	NA	1/CYL	VISI	NA	1/CYL	VISI	NA	1/CYL	VISI	NA	
15																
16		T cyl cover	CYLINDER TOP COVER TEMPS (per cylinder)	← NOT REQUIRED/RECOMMENDED →												
17		P_{rise}	PRESSURE RISE PRIOR TO OPENING OF INJ. VLV (per cylinder)	← NOT REQUIRED/RECOMMENDED →												
18		P_{injo}	DYNAMIC OPENING PRESS OF INJ VLV (per cylinder)	← NOT REQUIRED/RECOMMENDED →												
19		P_{injm}	MAXIMUM INJECTION PRESSURE (per cylinder)	← NOT REQUIRED/RECOMMENDED →												
20																
21		T_{injo}	TIME OF OPENING OF INJECTION VLV (per cylinder)	← NOT REQUIRED/RECOMMENDED →	(4)											(4) STRAIN GAGE POSSIBLE
22		L_{injo}	LENGTH OF OPENING OF INJECTION VLV (per cylinder)	← NOT REQUIRED/RECOMMENDED →	(4)											
23																
24																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
				SENSOR			SENSOR			SENSOR			SENSOR			
		SYMBOL	DESCRIPTION	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	
25	AIR & GAS PATH PROCESSES															
26		P_{baro}	ENGINE ROOM BAROMETRIC PRESSURE	1/ER	MAN	LOCG	1/ER	MAN	LOCG	1/ER	MAN	CRT	1/ER	MAN	LOCG	
27																
28		$T_{E.R.}$	ENGINE ROOM AMBIENT TEMPERATURE	1/ER	TG	LOCG	1/ER	TG	LOCG	1/ER	TG	CRT	1/ER	TG	LOCG	
29																
30		H_{rel}	ENGINE ROOM RELATIVE HUMIDITY	1/ER	HYGR	LOCG	1/ER	HYGR	LOCG	1/ER	HYGR	LOCG	1/ER	HYGR	LOCG	
31																
32		$\Delta P_{air\ filter}$	AIR PRESSURE DROP ACROSS T/C SCAV INLET FILTER (per T/C)	1 per T/C	MAN	LOCG	1 per T/C	MAN	LOCG	1 per T/C	ΔPT	CRT	1 per T/C	MAN	LOCG	
33																
34		Pcompr inlet	T/C COMPRESSOR INLET SUCTION PRESSURE (per T/C)	1 per T/C	PVG	LOCG	1 per T/C	MAN	LOCG	PVG	ABS PT	CRT	1 per T/C	PVG	LOCG	
35		ΔP_{compr}	AIR PRESSURE DROP ACROSS T/C COMPRESSOR HOUSING (per T/C)	1 per T/C	MAN	LOCG	1 per T/C	MAN	LOCG	1 per T/C	ΔPT	CRT	1 per T/C	MAN	LOCG	
36		Pcompr outlet	AIR PRESSURE AFTER T/C COMPRESSOR (per T/C)	1 per T/C	PG	LOCG	1 per T/C	PG	LOCG	1 per T/C	PT	CRT	1 per T/C	PG	LOCG	

Table 3-1

Engine Builders' and Licensees' Recommended Diagnostic Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
37	AIR & GAS PATH PROCESSES	$P_{sw\ in}$	SEA WATER PRESSURE AT INLET TO CHARGE AIR COOLER	1/CLR	PG	LOCG	1/CLR	PG	LOCG	1/CLR	PT	CRT	1/CLR	PG	LOCG	
38																
39		ΔP_{air}	AIR PRESSURE DROP ACROSS CHARGE AIR COOLER (per cooler)	1/CLR	MAN	LOCG	1/CLR	MAN	LOCG	1/CLR	PT	CRT	1/CLR	MAN	LOCG	
40		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/BANK	PG	LOCG	1/BANK	PG	LOCG	1/BANK	PT	CRT	1/BANK	PG	LOCG	
41																
42		Pturb inlet	EXHAUST GAS PRESSURE BEFORE TURBINE (per T/C)	1 per T/C	PG	LOCG	1 per T/C	PG	LOCG	1 per T/C	PT	CRT	1 per T/C	PG	LOCG	
43		Pturb outlet	EXHAUST GAS PRESSURE AFTER TURBINE (per T/C)	1 per T/C	PG	LOCG	1 per T/C	PG	LOCG	1 per T/C	PT	CRT	1 per T/C	PG	LOCG	
44																
45		P into boiler	EXHAUST GAS PRESSURE BEFORE WASTE HEAT BOILER	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	
46		P_{out}	EXHAUST GAS PRESSURE AFTER WASTE HEAT BOILER	1 BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	
47		% CO_2	EXHAUST GAS PERCENT CO_2	← NOT REQUIRED/RECOMMENDED →												
48		—	EXHAUST GAS CONDITION (opacity, etc.)	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	

Table 3-1
Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
49	AIR & GAS PATH PROCESSES	T air in comp	AIR TEMP AT INLET TO T/C COMPRESSOR (per T/C)	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	1 per T/C	RTD	CRT	1 per T/C	TG	LOCG	
50		T air out comp	AIR TEMP AT OUTLET OF T/C COMPRESSOR (per T/C)	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	1 per T/C	RTD	CRT	1 per T/C	TG	LOCG	
51																
52		T air in cool	AIR TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG	LOCG	1/CLR	TG	LOCG	1/CLR	RTD	CRT	1/CLR	TG	LOCG	
53		T air out cool	AIR TEMP AT OUTLET OF CHARGE AIR COOLER (per cooler)	1/CLR	TG	LOCG	1/CLR	TG	LOCG	1/CLR	RTD	CRT	1/CLR	TG	LOCG	
54																
55		T sw in cool	SEA WATER TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG	LOCG	1/CLR	TG	LOCG	1/CLR	RTD	CRT	1/CLR	TG	LOCG	
56		T sw out cool	SEA WATER TEMP AT OUTLET FROM CHARGE AIR COOLER (per cooler)	1/CLR	TG	LOCG	1/CLR	TG	LOCG	1/CLR	RTD	CRT	1/CLR	TG	LOCG	
57																
58		T_{scav}	SCAVENGING AIR BELT TEMPERATURE	1/BANK	TG	LOCG	1/BANK	TG	LOCG	1/BANK	RTD	CRT	1/BANK	TG	LOCG	
59																
60																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
61	AIR & GAS PATH PROCESSES	T exh indiv.	EXHAUST GAS TEMP AFTER CYLINDERS (individual)	1/CYL	TC	REMG (5)	1/CYL	TC	REMG (5)	1/CYL	TC	REMG (5)	1/CYL	TC	REMG (5)	(5) INCL. IN EXH. GAS MON.
62		T exh mean	EXHAUST GAS TEMP AFTER CYLINDERS (mean)	NA	NA	REMG (5)	NA	NA	REMG (5)	NA	NA	REMG (5)	NA	NA	REMG (5)	
63		T exh dev	EXHAUST GAS TEMP AFTER CYLINDERS (max deviation)	NA	NA	REMG (5)	NA	NA	REMG (5)	NA	NA	REMG (5)	NA	NA	REMG (5)	
64																
65		T exh to turb	EXHAUST GAS TEMP BEFORE TURBINE (per T/C)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	
66		T exh out turb	EXHAUST GAS TEMP AFTER TURBINE (per T/C)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	1 per T/C	TC	REMG (5)	
67		T_{in}	EXHAUST GAS TEMP BEFORE WASTE HEAT BOILER	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	
68		T_{out}	EXHAUST GAS TEMP AFTER WASTE HEAT BOILER	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	1/BLR	TC	REMG (5)	
69																
70		η_{turb}	TURBOCHARGER TURBINE EFFICIENCY	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
71		η_{compr}	TURBOCHARGER COMPRESSOR EFFICIENCY	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
72		η_{TC}	TURBOCHARGER OVERALL EFFICIENCY	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
73	CYLINDER COMPONENTS (RINGS)	—	PISTON RING COLLAPSE	NA	VISI	NA	NA	VISI	NA	1/CYL	IPBR	CRT	NA	VISI	NA	
74		—	PISTON RING BREAKAGE	NA	VISI	NA	NA	VISI	NA	1/CYL	IPBR	CRT	NA	VISI	NA	
75		—	PISTON RING STICKING	NA	VISI	NA	NA	VISI	NA	1/CYL	IPBR	CRT	NA	VISI	NA	
76		■■	PISTON RING WEAR	← MANUAL MEASUREMENTS →												
77																
78		HRS	PISTON RING OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
79	CYLINDER COMPONENTS (PISTONS)	—	PISTON GROOVE CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
80		■■	PISTON GROOVE WEAR	← MANUAL MEASUREMENTS →												
81		—	PISTON CROWN CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
82		■■	PISTON CROWN WEAR	← MANUAL MEASUREMENTS →												
83																
84		HRS	PISTON OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
85	CYLINDER COMPONENTS - LINERS	T_{liner} (upper)	CYLINDER LINER TEMPERATURE (upper) (blowby)	← NOT REQUIRED/RECOMMENDED →												
86																
87		T_{liner} (lower)	CYLINDER LINER TEMP (lower) (skirt seizures)	← NOT REQUIRED/RECOMMENDED →												
88		T_{scuff}	CYLINDER LINER TEMP (scuffing) (micro seizures)	← NOT REQUIRED/RECOMMENDED →												
89																
90		—	CYLINDER LINER CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
91		mm	CYLINDER LINER WEAR	← MANUAL MEASUREMENTS →												
92		HRS	CYLINDER LINER OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
93																
94		Kg/day	CYLINDER LINER LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
95		Kg/day	ENGINE LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
96																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
97	AIR/GAS PATH COMPONENTS (TURBOCHARGERS)	RPM	TURBOCHARGER SPEED (per T/C)	1 per T/C	ELPU	REMG	1 per T/C	ELPU	REMG	1 per T/C	ELPU	REMG	1 per T/C	ELPU	REMG	
98		mils	TURBOCHARGER VIBRATION LEVEL (per T/C)	1 per T/C	VIBPU	REMG	NR	NR	NR	1 per T/C	VIBPU	REMG	1 per T/C	VIBPU	REMG	
99																
100		TLO in	TURBOCHARGER LUBE OIL INLET TEMP (per T/C)	NA	NA	NA	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	
101		TLO out	TURBOCHARGER LUBE OIL OUTLET TEMP (per T/C)	NA	NA	NA	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	1 per T/C	TG	LOCG	
102		PLO in	TURBOCHARGER LUBE OIL INLET PRESSURE (per T/C)	NA	NA	NA	1 per T/C	PG	LOCG	1 per T/C	PG	LOCG	1 per T/C	PG	LOCG	
103																
104	AIR/GAS PATH COMPONENTS (EXH. VLV)	mm	SPINDLE GUIDE CLEARANCES	← MANUAL MEASUREMENTS →												
105		mm	RING CLEARANCES	← MANUAL MEASUREMENTS →												
106		mm	SPINDLE WEAR	← MANUAL MEASUREMENTS →												
107		mm	SEAT WEAR	← MANUAL MEASUREMENTS →												
108																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
109	AIR/GAS PATH COMPONENTS (EXHAUST VALVES)	--	SEAT BURNING	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
110		--	SPRING CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
111																
112		■■	HYDRAULIC LINER DIAMETER	← MANUAL MEASUREMENT →												
113		■■	ROLLER CLEARANCES	← MANUAL MEASUREMENTS →												
114		--	CAM & ROLLER SURFACES	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
115		--	HOUSING & GUIDE SURFACES	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
116																
117		HRS	OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
118																
119																
120																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
121	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	MAIN BEARING OIL OUTLET TEMPERATURE	NR	NR	NR	NR	NR	NR	NR	NR	NR	1/BRG	OIL RTD	REMG	
122		T_{brg}	MAIN BEARING HOUSING & SHELL TEMPERATURE	1/BRG	SHELL RTD	REMG	1/BRG	SHELL RTD	REMG	1/BRG/ 1/ENG	RTD/ VIBPU	CRT	NR	NR	NR	
123		mm	MAIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →												
124																
125		$T_{oil\ out}$	CRANK PIN BEARING OIL OUTLET TEMPERATURE	NR	NR	NR	NR	NR	NR	1/BRG	RTD	CRT	NR	NR	NR	
126		T_{brg}	CRANK PIN BEARING HOUSING & SHELL TEMPERATURE	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
127		mm	CRANK PIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →												
128																
129																
130																
131																
132																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
133	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	THRUST BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	1/BRG	RTD	REMG	NR	NR	NR	1/BRG	RTD	REMG	
134		T_{brg}	THRUST BEARING PAD METAL TEMPERATURE	NR	NR	NR	NR	NR	NR	1/BRG	RTD	CRT	NR	NR	NR	
135		mm	THRUST BEARING PAD CLEARANCES	← MANUAL MEASUREMENTS →												
136		mm	CAMSHAFT BEARING CLEARANCES	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
137		PPM	CRANKCASE OIL MIST DETECTION	AS REQD	OMM	REMG	AS REQD	OMM	REMG	AS REQD	OMM	REMG	AS REQD	OMM	REMG	
138		mm	CONTROL DRIVE GEAR BACKLASH	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
139		--	LUBE OIL ANALYSIS (ferrography, etc)	NA	LAB ANALY	NA	NA	LAB ANALY	NA	NA	LAB ANALY	NA	NA	LAB ANALY	NA	
140																
141		mm	CRANKSHAFT/MAIN BEARING DISPLACEMENT	← MANUAL MEASUREMENTS →												BRIDGE GAUGE
142																
143		mm	CRANKWEB DEFLECTION ANALYSIS	← MANUAL MEASUREMENTS →												DIAL GAUGE
144																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
145	HEAT EXCHANGER COMPONENTS - MAIN ENGINE	$\Delta T_{F.W.}$	JACKET WATER F.W. TEMP △ ACROSS JACKET WATER COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
146		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS JACKET WATER COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
147																
148		$\Delta T_{F.W}$	PISTON COOLING F.W. TEMP △ ACROSS PISTON COOLER	NA	NA	NA	2/CLR (6)	TG	LOCG	NA	NA	NA	NA	NA	NA	(6) INJECTOR COOLER
149		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS PISTON COOLER	NA	NA	NA	2/CLR (6)	TG	LOCG	NA	NA	NA	NA	NA	NA	
150																
151		$\Delta T_{L.O.}$	MAIN LUBE OIL TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
152		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
153																
154		$\Delta T_{L.O.}$	TURBOCHARGER LUBE OIL TEMP △ ACROSS T/C LUBE OIL COOLER	NA	NA	NA	NA	NA	NA	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
155		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS T/C LUBE OIL COOLER	NA	NA	NA	NA	NA	NA	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
156																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
157	HEAT EXCHANGER COMPONENTS-MAIN	$\Delta T_{L.O.}$	CAMSHAFT LUBE OIL TEMP △ ACROSS CAMSHAFT L.O. COOLER	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
158		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS CAMSHAFT L.O. COOLER	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
159																
160		--	FRESH WATER COOLING ADDITIVE ADEQUACY	← MANUAL WATER ANALYSIS →												(PH AND SALINITY)
161	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{F.W.}$	AUX ENG CYL FRESH WATER TEMP △ ACROSS COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
162		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS FRESH WATER COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
163																
164		ΔT_{air}	AUX ENG CHARGE AIR TEMP △ ACROSS CHARGE AIR COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
165		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS CHARGE AIR COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
166																
167		$\Delta T_{L.0}$	AUX ENG LUBE OIL TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	
168		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	2/CLR	TG	LOCG	

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
169	FUEL OIL DELIVERY COMPONENTS	T f.o. to htr	FUEL OIL TEMP BEFORE PREHEATERS	1/HTR	TG	LOCG	1/HTR	TG	LOCG	1/HTR	TG	LOCG	1/HTR	TG	LOCG	
170		T F.O. visc.	FUEL OIL TEMP AFTER PREHEATERS AT VISCOMETER	1/VISC	TG	LOCG	1/VISC	TG	LOCG	1/VISC	TG	LOCG	1/VISC	TG	LOCG	
171		T f.o. to eng	FUEL OIL TEMP AT ENGINE INLET	1/ENG	TG	LOCG	1/ENG	TG	LOCG	1/ENG	TG	REMG	1/ENG	TG	LOCG	
172																
173		P in fltr	FUEL OIL PRESSURE BEFORE FILTERS	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	
174		P out fltr	FUEL OIL PRESSURE AFTER FILTERS AT ENGINE INLET	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	
175																
176		$Q_{F.O.}$	FUEL OIL CONSUMPTION/FLOW RATE	1/ENG	FM	LOCG	1/ENG	FM	LOCG	1/ENG	FM	LOCG	1/ENG	FM	LOCG	
177																
178		T in sep.	FUEL OIL TEMPERATURE BEFORE SEPARATOR	1/SEP	TG	LOCG	1/SEP	TG	LOCG	1/SEP	TG	LOCG	1/SEP	TG	LOCG	
179		Q % flow	FUEL OIL PERCENT THROUGHPUT AT SEPARATORS	1/SEP	FM	LOCG	1/SEP	FM	LOCG	1/SEP	FM	LOCG	1/SEP	FM	LOCG	
180																

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
181	FUEL OIL DELIVERY COMPONENTS	cSt	FUEL OIL VISCOSITY AT 50° C	← LAB ANALYSIS →												
182		S.G/ρ	FUEL OIL SPECIFIC GRAVITY OR DENSITY	← LAB ANALYSIS →												
183		% S	FUEL OIL SULFUR CONTENT	← LAB ANALYSIS →												
184		% V	FUEL OIL VANADIUM CONTENT	← LAB ANALYSIS →												
185		h_i	FUEL OIL HEATING VALUE	← LAB ANALYSIS →												
186																
187	VESSEL FACTORS DESIGN	Ft/m	DRAFT (FWD/AFT) BALLAST	← DESIGN DATA →												
188		Ft or m	DRAFT (FWD/AFT) LADEN	← DESIGN DATA →												
189		DWT	DEADWEIGHT/BALLAST	← DESIGN DATA →												
190		DWT	DEADWEIGHT/LADEN	← DESIGN DATA →												
191		Knts	SPEED (LADEN/LIGHT)	← DESIGN DATA →												
192		mm	PROPELLER PITCH	← DESIGN DATA →												

Table 3-1

Diesel Engine Manufacturer/Licensee Recommended Practices

Medium Speed/4 Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		MANUFACTURER "A"			MANUFACTURER "B"			MANUFACTURER "C"			MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
193	VESSEL FACTORS - EXTERNAL	FT/m	DRAFT (FWD & AFT)	2/SHIP	(7)	(7)	2/SHIP	(7)	(7)	2/SHIP	(7)	(7)	2/SHIP	(7)	(7)	(7) VISI OR SPEC. EQUIP
194																
195		KNTS	SPEED (BY LOG)	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	
196		KNTS	SPEED (OVER GROUND)	OBSERVED												
197		$Min.^{-1}$	RPM (SHAFT/ENGINE)	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	
198		%	PROPELLER SLIP	NA	CALC	NA	NA	CALC	NA	NA	CALC	NA	NA	CALC	NA	
199																
200		FT/m	WATER DEPTH	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	
201		#	SEA STATE	OBSERVED												
202		DIR	SEA DIRECTION	OBSERVED												
203		#	WIND FORCE	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	
204		DIR	WIND DIRECTION	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	

FIGURE 3-15

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 3-2

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
AN	Anemometer	HTR	Heater
ANALY	Analyzer	LIN	Liner
APPT	Air Cooled Piezo-electric Pressure Transducer	NA	Not Applicable
		NCTC	Ni/Cr/Ni Ther-mocouple
BLR	Boiler	OMM	Oil Mist Sep-arator
BRG	Bearing		
CALC	Calculated	OSC	Oscilloscope
CA	Chromel/Alumel	PG	Pressure Gage
CLR	Cooler	PO	Printer
CVR	Cover	POTT	Potentiometric Transducer
CYL	Cylinder	PP	Proximity Probe
CRT	Cathode Ray Tube		
DSDR	Depth Sounder	PPT	Piezoelectric Pressure Trans-ducer
DD	Digital Display		
DIG	Digital	PROP	Propeller
ENG	Engine	PT	Pressure Trans-ducer
ER	Engine Room	RE	Rotary Encoder
EXH	Exhaust	REMG	Remote Gage
FLTR	Filter	RTD	Resistance Temp-erature
FM	Flow Meter	SEP	Separator
FR	Fuel Rack	SPLG	Speed Log
HSET	High Speed Elec-tric Tachometer	SYNT	Synchronous Transmitter

FIGURE 3-15

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 3-2 CONTINUED

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
TC	Thermocouple	&	and
T/C	Turbocharger	/	or
HYGR	Hygrometer		
ICD	Indicator Card		
IPP	Inductive Proximity Probe		
IPSS	Inductive Piston Stroke Sensor		
LOCG	Local Gage		
MAN	Manometer		
MEAS	Measure		
MGIP	Magnetic Inductive Probe		
MIP	Mean Indicated Pressure		
MPP	Magnetic Proximity Probe		
MPSR	Magnetic Probe with Special Rings		
T/C	Turbocharger		
TG	Temperature Gage		
TGEN	Tachometer Generator		
TM	Torsion Meter		
UPPT	Uncooled Piezoelectric Pressure Transducer		
VISI	Visual Inspection		
Δ	Differential		

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
1	CYLINDER COMBUSTION PROCESSES	Pmi/or MIP	MEAN INDICATED PRESSURE (per cylinder)	NR	NR	NR	1/ENG	UPPT APPT	DIG + PO	1/ENG	PT/ ICD	DIG/ LOGG	1/ENG	UPPT	CRT+ DL	1/ENG	APPT	DIG+ OSC	
2																			
3		P_{max}	MAXIMUM OR FIRING PRESSURE (per cylinder)	1/CYL	UPPT	DIG + PO	ITEM 1 (1)	UPPT APPT	DIG + PO	ITEM 1 (1)	PT/ ICD	LOGG/ DIG	ITEM 1 (1)	UPPT	CRT+ DL	ITEM 1 (1)	APPT	DIG+ OSC	(1) COMMON SENSOR
4		P_{comp}	COMPRESSION PRESSURE (per cylinder)	ITEM 3 (1)	UPPT	DIG + PO	ITEM 1 (1)	UPPT/ APPT	DIG + PO	ITEM 1 (1)	PT/ ICD	DIG/ LOGG	ITEM 1 (1)	UPPT	CRT+ DL	ITEM 1 (1)	APPT	DIG+ OSC	
5		P_{exp}	EXPANSION PRESSURE (per cylinder)	NR	NR	NR	ITEM 1 (1)	UPPT/ APPT	DIG + PO	NR	NR	NR	ITEM 1 (1)	UPPT		ITEM 1 (1)	APPT		
6																			
7		$\propto P_{max}$	ANGLE OR TIME OF P_{max} (per cylinder)	1/CYL	UPPT & RE	DIG + PO	1/CYL	IPSS	DIG + PO	NR	NR	NR	1/ENG	UPPT & RE	CRT+ DL	1/ENG	APPT &MPP	DIG+ OSC	
8		$\propto P_{comp}$	ANGLE OR TIME OF P_{comp} (per cylinder)	1/CYL	UPPT & RE	DIG + PO	1/CYL	IPSS	DIG + PO	NR	NR	NR	1/ENG	UPPT & RE	CRT+ DL	1/ENG	APPT &MPP	DIG+ OSC	
9																			
10		RPM	SPEED AT ENGINE FLYWHEEL	1/ENG	RET	DIG + PO	1/ENG	IPP	DIG + PO	1/ENG	TGEN /PP	REMG	1/ENG	RET	CRT+ DL	1/ENG	MPP	DIG	
11		T/BHP	TORQUE/BHP AT ENGINE (value, method & location)	NA	FR/ TM	DIG + PO	NA	FR/TM MIP	DIG + PO	NA	FR/ MIP	REMG	NA	FR/ MIP	CRT+ DL	NA	FR/TM MIP	DIG	
12		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ BANK	PT	DIG + PO	1/ BANK	PT	DIG + PO	1/ BANK	PT	REMG	1/ BANK	PT	CRT+ DL	1/ BANK	PT	DIG	

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
13	FUEL OIL INJECTION PROCESSES	POS & % DROOP	FUEL GOVERNOR POSITION AND % SPEED DROOP	1/ENG	SYNT	REMG	1/ENG	VISI	NA	1/ENG	VISI	NA	1/ENG	SYNT	REMG	1/ENG	VISI	NA	
14		INDEX	FUEL PUMP INDEX (per cylinder)	1/CYL	VISI	NA	1/CYL	POTT/ VISI	REMG	1/CYL	VISI	NA	1/CYL	VISI	NA	1/CYL	POTT/ VISI	REMG	
15																			
16		T cyl cover	CYLINDER TOP COVER TEMPS (per cylinder)	NR	NR	NR	2/CVR	(2) CATC	(2)	NR	NR	NR	NR	NR	NR	NR	NR	NR	(2) IF INSTALLED ALM ONLY
17		P_{rise}	PRESSURE RISE PRIOR TO OPENING OF INJ VLV (per cylinder)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
18		P_{injo}	DYNAMIC OPENING PRESS OF INJ VLV (per cylinder)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
19		P_{injm}	MAXIMUM INJECTION PRESSURE (per cylinder)	1/CYL	APPT	DIG + PO	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
20																			
21		T_{injo}	TIME OF OPENING OF INJECTION VLV (per cylinder)	1/CYL	APPT & RE	DIG + PO	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
22		L_{injo}	LENGTH OF OPENING OF INJECTION VLV (per cylinder)	1/CYL	APPT &RE	DIG + PO	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	
23																			
24																			

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
25	AIR & GAS PATH PROCESSES																		
26		P_{baro}	ENGINE ROOM BAROMETRIC PRESSURE	1/ER	PG/ MAN	LOCG	1/ER	PG/ MAN	LOCG	1/ER	PG/ MAN	LOCG	1/ER	PG/ MAN	LOCG	1/ER	PG/ MAN	LOCG	
27																			
28		$T_{E.R.}$	ENGINE ROOM AMBIENT TEMPERATURE	1/ER	TG	LOCG	1/ER	TG	LOCG	1/ER	TG	LOCG	1/ER	TG	LOCG	1/ER	TG	LOCG	
29																			
30		H_{rel}	ENGINE ROOM RELATIVE HUMIDITY	NR	NR	NR	1/ENG	HYGR	LOCG	1/ENG	HYGR	LOCG	NR	NR	NR	1/ENG	HYGR	LOCG	
31																			
32		ΔPair fltr	AIR PRESSURE DROP ACROSS T/C SCAV INLET FILTER (per T/C)	1 per T/C	ΔPT/ MAN	DIG/ LOCG	1 per T/C	ΔPT/ MAN	REMG	NR	NR	NR	1 per T/C	ΔPT/ MAN	REMG/ LOCG	1 per T/C	ΔPT/ MAN	REMG/ LOCG	
33																			
34		Pcompr inlet	T/C COMPRESSOR INLET SUCTION PRESSURE (per T/C)	1 per T/C	ABS PT	DIG + PO	1 per T/C	ABS/ PGPT	LOCG/ REMG	1 per T/C	PG	LOCG	1 per T/C	PG/ PT	LOCG/ REMG	1 per T/C	PG/ PT	LOCG/ REMG	
35		ΔP compr	AIR PRESSURE DROP ACROSS T/C COMPRESSOR HOUSING (per T/C)	1 per T/C	ΔPT/ MAN	DIG/ LOCG	1 per T/C	ΔPT/ MAN	REMG/ LOCG	NR	NR	NR	1 per T/C	ΔPT/ MAN	LOCG/ REMG	1 per T/C	ΔPT/ MAN	LOCG/ REMG	
36		Pcompr outlet	AIR PRESSURE AFTER T/C COMPRESSOR (per T/C)	1 per T/C	PT	DIG + PO	NR	NR	NR	1 per T/C	PG/ PT	LOCG/ REMG	1 per T/C	PG/ PT	LOCG/ REMG	NR	NR	NR	

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
37	AIR & GAS PATH PROCESSES	P sw in	SEA WATER PRESSURE AT INLET TO CHARGE AIR COOLER	1/CLR	PG/ PT	LOCG/ DIG	NR	NR	NR	1/CLR	PG/ PT	LOCG/ REMG	1/CLR	PG/ PT	LOCG/ REMG	NR	NR	NR	
38																			
39		ΔP air cooler	AIR PRESSURE DROP ACROSS CHARGE AIR COOLER (per cooler)	1/CLR	ΔPT/ MAN	DIG/ LOCG	1/CLR	ΔPT/ MAN	REMG/ LOCG	1/CLR	ΔPT/ MAN	LOCG/ REMG	1/CLR	ΔPT/ MAN	LOCG/	1/CLR	ΔPT/ MAN	LOCG/ REMG	
40		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ BANK	PG/ PT	DIG + PO	1/ BANK	PG/ PT	LOCG/ REMG	1/ BANK	PG/ PT	LOCG/	1/ BANK	PG/ PT	LOCG/ REMG	1/ BANK	PG/ PT	LOCG/ REMG	
41																			
42		Pturb inlet	EXHAUST GAS PRESSURE BEFORE TURBINE (per T/C)	1 per T/C	PT	DIG + PO	1 per T/C	PG/ PT	LOCG/ REMG	1 per T/C	PT	REMG	NR	NR	NR	1 per T/C	PG/ PT	LOCG/ REMG	
43		Pturb outlet	EXHAUST GAS PRESSURE AFTER TURBINE (per T/C)	1 per T/C	PT	DIG + PO	1 per T/C	PG/ PT	LOCG/ REMG	1 per T/C	PT	REMG	NR	NR	NR	1 per T/C	PG/ PT	LOCG/ REMG	
44																			
45		P into boiler	EXHAUST GAS PRESSURE BEFORE WASTE HEAT BOILER	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	
46		P_{out}	EXHAUST GAS PRESSURE AFTER WASTE HEAT BOILER	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	1/BLR	PG	LOCG	
47		% CO_2	EXHAUST GAS PERCENT CO_2	NR	NR	NR	NR	NR	NR	1/EXH	GAS ANALY	REMG	NR	NR	NR	NR	NR	NR	
48			EXHAUST GAS CONDITION (opacity, etc.)	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
49	AIR & GAS PATH PROCESSES	T air in comp	AIR TEMP AT INLET TO T/C COMPRESSOR (per T/C)	1 per T/C	TG/ RTD	LOCG/ DIG	1 per T/C	RTD	REMG	1 per T/C	TG/ RTD	LOCG/ REMG	1 per T/C	TG/ RTD	LOCG/ REMG	1 per T/C	TG/ RTD	LOCG/ REMG	
50		T air out comp	AIR TEMP AT OUTLET OF T/C COMPRESSOR (per T/C)	1 per T/C	TG/ RTD	LOCG/ DIG	NR	NR	NR	NR	NR	NR	1 per T/C	TG/ RTD	LOCG/ REMG	NR	NR	NR	
51																			
52		T air in cool	AIR TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD	LOCG/ DIG	1/CLR	RTD	REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	
53		T air out cool	AIR TEMP AT OUTLET OF CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD	LOCG/ DIG	1/CLR	RTD	REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	
54																			
55		T sw in cool	SEA WATER TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	
56		T sw out cool	SEA WATER TEMP AT OUTLET FROM CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	1/CLR	TG/ RTD	LOCG/ REMG	
57																			
58		T_{scav}	SCAVENGING BELT AIR TEMPERATURE	1/ BANK	TG/ RTD	LOCG/ REMG	1/ BANK	RTD	REMG	1/ BANK	RTD	REMG	1/ BANK	TG/ RTD	LOCG/ REMG	1/ BANK	TG/ RTD	LOCG/ REMG	
59																			
60																			

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
61	AIR & GAS PATH PROCESSES	T exh indiv.	EXHAUST GAS TEMP AFTER CYLINDERS (individual)	1/CYL	TC	REMG (3)	1/CYL	TC	REMG (3)	1/CYL	TC	REMG (3)	1/CYL	RTD	REMG (3)	1/CYL	TC	REMG (3)	(3) INCL. IN EXH. GAS MON
62		T exh mean	EXHAUST GAS TEMP AFTER CYLINDER (mean)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	
63		T exh dev.	EXHAUST GAS TEMP AFTER CYLINDERS (max. deviation)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	NA	NA	REMG (3)	
64																			
65		T exh to turb	EXHAUST GAS TEMP BEFORE TURBINE (per T/C)	1 per T/C	TC	REMG (3)	1 per T/C	TC	REMG (3)	1 per T/C	TC	REMG (3)	1 per T/C	RTD	REMG (3)	1 per T/C	TC	REMG (3)	
66		T exh out turb	EXHAUST GAS TEMP AFTER TURBINE (per T/C)	1 per T/C	TC	REMG (3)	1 per T/C	TC	REMG (3)	1 per T/C	TC	REMG (3)	1 per T/C	RTD	REMG (3)	1 per T/C	TC	REMG (3)	
67		T_{in}	EXHAUST GAS TEMP BEFORE WASTE HEAT BOILER	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	
68		T_{out}	EXHAUST GAS TEMP AFTER WASTE HEAT BOILER	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	1/BLR	TC	REMG (3)	
69		η turb	TURBOCHARGER TURBINE EFFICIENCY	NA	NA	DIG + PO	NA	NA	CALC	NA	NA	NR	NA	NA	CALC	NA	NA	NR	
70		η compr	TURBOCHARGER COMPRESSOR EFFICIENCY	NA	NA	DIG + PO	NA	NA	CALC	NA	NA	NR	NA	NA	CALC	NA	NA	NR	
71		η TC	TURBOCHARGER OVERALL EFFICIENCY	NA	NA	DIG + PO	NA	NA	CALC	NA	NA	NR	NA	NA	CALC	NA	NA	NR	
72																			

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
73	CYLINDER COMPONENTS (RINGS)	—	PISTON RING COLLAPSE	1/CYL	MPSR	PO	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	2/CYL	MGIP	REMG	
74		—	PISTON RING BREAKAGE	1/CYL	MPSR	PO	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	2/CYL	MGIP	REMG	
75		—	PISTON RING STICKING	1/CYL	MPSR	PO	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	2/CYL	MGIP	REMG	
76		MM	PISTON RING WEAR	1/CYL	MPSR	PO	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NR	VISI	NA	
77																			
78		HRS	PISTON RING OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
79	CYLINDER COMPONENTS (PISTONS)	—	PISTON GROOVE CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
80		MM	PISTON GROOVE WEAR	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
81		—	PISTON CROWN CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
82		MM	PISTON CROWN WEAR	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
83																			
84		HRS	PISTON OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
85	CYLINDER COMPONENTS - LINERS	TLiner (upper)	CYLINDER LINER TEMPERATURE (blow-by)	NR	NR	NR	4/LIN	NCTC	ALM (4)	NR	NR	NR	4/LIN	NCTC	REMG	NR	NR	NR	(4) IF INSTALLED ALARM ONLY
86																			
87		TLiner (lower)	CYLINDER LINER TEMP (lower) (skirt seizure)	NR	NR	NR	ITEM 25	NCTC	ALM (4)	NR	NR	NR	NR	NR	NR	NR	NR	NR	
88		T_{scuff}	CYLINDER LINER TEMP (scuffing) (micro seizures)	1/LIN	NCTC	DIG + PO	ITEM 25	NCTC	REMG	NR	NR	NR	1/LIN	NCTC	REMG	NR	NR	NR	
89																			
90		—	CYLINDER LINER CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
91		MM	CYLINDER LINER WEAR	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
92		HRS	CYLINDER LINER OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
93																			
94		Kg/Day	CYLINDER LINER LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
95		Kg/Day	ENGINE LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	NA	NA	LOG	
96																			

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
97	AIR/GAS PATH COMPONENTS (TURBOCHARGERS)	RPM	TURBOCHARGER SPEED (per T/C)	1/TC	HSET	DIG + PO	1/TC	HSET	REMG	1/TC	HSET	REMG	1/TC	HSET	REMG	1/TC	HSET	REMG	
98		MILS	TURBOCHARGER VIBRATION LEVEL (per T/C)	NOT REQUIRED/RECOMMENDED															
99																			
100		$T_{LO\ in}$	TURBOCHARGER LUBE OIL INLET TEMP (per T/C)	NR	NR	NR	1/TC	TG/ RTD	LOCG/ REMG	NR	NR	NR	NR	NR	NR	1/TC	TG/ RTD	LOCG/ REMG	
101		$T_{LO\ out}$	TURBOCHARGER LUBE OIL OUTLET TEMP (per T/C)	NR	NR	NR	1/TC	TG/ RTD	LOCG/ REMG	1/TC	RTD/ TG	LOCG/ REMG	NR	NR	NR	1/TC	TG/ RTD	LOCG/ REMG	
102		$P_{LO\ IN}$	TURBOCHARGER LUBE OIL INLET PRESSURE (per T/C)	1/TC	PT	REMG	NR	NR	NR	1/TC	PG/ PT	LOCG/ REMG	NR	NR	NR	NR	NR	NR	
103																			
104	AIR/GAS PATH COMPONENTS (EXH. VLV)	MM	SPINDLE GUIDE CLEARANCE		NOT REQUIRED			MANUAL MEASUREMENTS AS REQUIRED			NOT REQUIRED			NOT REQUIRED			MANUAL MEASUREMENTS- AS REQUIRED		
105		MM	RING CLEARANCE																
106		MM	SPINDLE WEAR																
107		MM	SEAT WEAR																
108																			

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
109	AIR/GAS PATH COMPONENTS (EXHAUST VALVES)	—	SEAT BURNING		NOT REQUIRED			MANUAL MEASUREMENTS - AS REQUIRED			NOT REQUIRED			NOT REQUIRED			MANUAL MEASUREMENTS-AS REQUIRED		
110		—	SPRING CONDITION																
111																			
112		MM	HYDRAULIC LINER DIAMETER																
113		MM	ROLLER CLEARANCES																
114		—	CAM & ROLLER SURFACES																
115		—	HOUSING & GUIDE SURFACES																
116																			
117		HRS	OPERATING HOURS																
118																			
119																			
120																			

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
121	DRIVE TRAIN BEARING COMPONENTS	T oil out	MAIN BEARING OIL OUTLET TEMPERATURE	(5)	RTD	REMG	NR	NR	NR	1/ENG	RTD	REMG	(5)	RTD	REMG	NR	NR	NR	(5) NO. OF BRGS + 1
122		T_{brg}	MAIN BEARING HOUSING & SHELL TEMPERATURE	← NOT REQUIRED/RECOMMENDED →															
123		MM	MAIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →															
124																			
125		T oil out	CRANK PIN BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	NR	NR	NR	1/ENG	RTD	REMG	1/BRG	RTD	REMG	NR	NR	NR	
126		T_{brg}	CRANK PIN BEARING HOUSING & SHELL TEMPERATURE	← NOT REQUIRED/RECOMMENDED →															
127		MM	CRANK PIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →															
128																			
129		T_{oil}	CROSSHEAD BEARING OIL OUTLET TEMPERATURES	2/BRG	RTD	REMG	NR	NR	NR	1/ENG	RTD	REMG	2/BRG	RTD	REMG	NR	NR	NR	
130		T_{brg}	CROSSHEAD BEARING HOUSING & SHELL TEMPERATURE	← NOT REQUIRED/RECOMMENDED →															
131		MM	CROSSHEAD BEARING CLEARANCES	← MANUAL MEASUREMENTS →															
132		MM	GUIDESHOE CLEARANCES	MANUAL MEAS.			NR	NR	NR	MANUAL MEAS.			MANUAL MEAS.			NR	NR	NR	

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
133	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	THRUST BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	NR	NR	NR	1/BRG	RTD	REMG	1/BRG	RTD	REMG	NR	NR	NR	
134		T_{brg}	THRUST BEARING PAD METAL TEMPERATURE	NR	NR	NR	1/BRG	RTD	REMG	NR	NR	NR	NR	NR	NR	1/BRG	RTD	REMG	
135		MM	THRUST BEARING PAD CLEARANCES	MANUAL MEASUREMENTS															
136		MM	CAMSHAFT BEARING CLEARANCES	MANUAL MEASUREMENTS															
137		PPM	CRANKCASE OIL MIST DETECTION	1/CYL	OMM	REMG	1/CYL	OMM	REMG	1/CYL	OMM	REMG	1/CYL	OMM	REMG	1/CYL	OMM	REMG	
138		MM	CONTROL DRIVE GEAR BACKLASH	MANUAL MEASUREMENTS															
139		—	LUBE OIL ANALYSIS (ferrography, etc)	NOT REQUIRED/RECOMMENDED															
140																			
141		MM	CRANKSHAFT MAIN BEARING DISPLACEMENT	MANUAL MEASUREMENTS															BRIDGE GAUGE
142																			
143		MM	CRANKWEB DEFLECTION ANALYSIS	MANUAL MEASUREMENTS															DIAL GAUGE
144																			

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
145	HEAT EXCHANGER COMPONENTS - MAIN	$\Delta T_{F.W.}$	JACKET WATER F.W. TEMP ACROSS JACKET WATER COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
146		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS JACKET WATER COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
147																			
148		$\Delta T_{F.W.}$	PISTON COOLING F.W. TEMP ACROSS PISTON COOLER	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	
149		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS PISTON COOLER	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	
150																			
151		$\Delta T_{L.O.}$	MAIN LUBE OIL TEMP ACROSS LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
152		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
153																			
154		$\Delta T_{L.O.}$	TURBOCHARGER LUBE OIL TEMP ACROSS T/C LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
155		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS T/C LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
156																			

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
157	HEAT EXCHANGER COMPONENTS-MAIN	$\Delta T_{L.O.}$	CAMSHAFT LUBE OIL TEMP ACROSS CAMSHAFT L.O. COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
158	HEAT EXCHANGER COMPONENTS-MAIN	$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS CAMSHAFT L.O. COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	NR	NR	NR	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
159	HEAT EXCHANGER COMPONENTS-MAIN																		
160	HEAT EXCHANGER COMPONENTS-MAIN	—	FRESH WATER COOLING ADDITIVE ADEQUACY	← MANUAL WATER ANALYSIS →															PH & SALINITY
161	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{F.W}$	AUX ENG CYL FRESH WATER TEMP ACROSS COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
162	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{S.W}$	SALT WATER TEMP ACROSS FRESH WATER COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
163	HEAT EXCHANGER COMPONENTS AUXILIARY																		
164	HEAT EXCHANGER COMPONENTS AUXILIARY	ΔT_{air}	AUX ENG CHARGE AIR TEMP ACROSS CHARGE AIR COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
165	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{S.W}$	SALT WATER TEMP ACROSS CHARGE AIR COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
166	HEAT EXCHANGER COMPONENTS AUXILIARY																		
167	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{L.O}$	AUX ENG LUBE OIL TEMP ACROSS LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	
168	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{S.W}$	SALT WATER TEMP ACROSS LUBE OIL COOLER	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	2/CLR	TG/ RTD	LOCG/ REMG	

Table 3-2

Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
169	FUEL OIL DELIVERY COMPONENTS	$T_{F.O.W.}$	FUEL OIL TEMP BEFORE PREHEATERS	NR	NR	NR	1/HTR	TG/ RTD	LOCG/ REMG	1/HTR	TG/ RTD	LOCG/ REMG	NR	NR	NR	1/HTR	TG/ RTD	LOCG/ REMG	
170		T F.O. visc.	FUEL OIL TEMP AFTER PREHEATERS AT VISCOMETER	1/VIS	TG/ RTD	LOCG/ DIG	1/VIS	TG/ RTD	LOCG/ REMG	1/VIS	TG/ RTD	LOCG/ REMG	1/VIS	TG/ RTD	LOCG/ REMG	1/VIS	TG/ RTD	LOCG/ REMG	
171		T F.O. in	FUEL OIL TEMP AT ENGINE INLET	1/ENG	TG/ RTD	LOCG/ DIG	1/ENG	TG/ RTD	LOCG/ REMG	1/ENG	TG/ RTD	LOCG/ REMG	1/ENG	TG/ RTD	LOCG/ REMG	1/ENG	TG/ RTD	LOCG/ REMG	
172																			
173		P in fltr	FUEL OIL PRESSURE BEFORE FILTER	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	1/FLTR	PG	LOCG	
174		P out fltr	FUEL OIL PRESSURE AFTER FILTER AT ENGINE INLET	1/ENG	PG/ PT	LOCG/ DIG	1/ENG	PG/ PT	LOCG/ REMG	1/ENG	PG/ PT	LOCG/ REMG	1/ENG	PG/ PT	LOCG/ REMG	1/ENG	PG/ PT	LOCG/ REMG	
175																			
176		$Q_{F.O.}$	FUEL OIL CONSUMPTION/ FLOW RATE	1/ENG	FM	LOCG	1/ENG	FM	LOCG	1/ENG	FM	LOCG	1/ENG	FM	LOCG	1/ENG	FM	LOCG	
177																			
178		T in sep.	FUEL OIL TEMPERATURE BEFORE SEPARATOR	1/SEP	TG	LOCG	1/SEP	TG	LOCG	1/SEP	TG	LOCG	1/SEP	TG	LOCG	1/SEP	TG	LOCG	
179		Q % flow	FUEL OIL PERCENT THROUGHPUT AT SEPARATORS	1/SEP	FM	LOCG	1/SEP	FM	LOCG	1/SEP	FM	LOCG	1/SEP	FM	LOCG	1/SEP	FM	LOCG	
180																			

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER		ENGINE MFG/LICENSEE "A"			ENGINE MFG/LICENSEE "B"			ENGINE MFG/LICENSEE "C"			ENGINE MFG/LICENSEE "D"			ENGINE MFG/LICENSEE "E"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
181	FUEL OIL DELIVERY COMPONENTS	cSt	FUEL OIL VISCOSITY AT 50° C	←							LAB ANALYSIS							→	
182	FUEL OIL DELIVERY COMPONENTS	S.G/P	FUEL OIL SPECIFIC GRAVITY OR DENSITY	←							LAB ANALYSIS							→	
183	FUEL OIL DELIVERY COMPONENTS	%S	FUEL OIL SULFUR CONTENT	←							LAB ANALYSIS							→	
184	FUEL OIL DELIVERY COMPONENTS	%V	FUEL OIL VANADIUM CONTENT	←							LAB ANALYSIS							→	
185	FUEL OIL DELIVERY COMPONENTS	h_i	FUEL OIL HEATING VALUE	←							LAB ANALYSIS							→	
186	FUEL OIL DELIVERY COMPONENTS																		
187	VESSEL FACTORS DESIGN	Ft/m	DRAFT (FWD/AFT) BALLAST	←							DESIGN DATA							→	
188	VESSEL FACTORS DESIGN	Ft or m	DRAFT (FWD/AFT) LADEN	←							DESIGN DATA							→	
189	VESSEL FACTORS DESIGN	DWT	DEADWEIGHT/BALLAST	←							DESIGN DATA							→	
190	VESSEL FACTORS DESIGN	DWT	DEADWEIGHT/LADEN	←							DESIGN DATA							→	
191	VESSEL FACTORS DESIGN	Knts	SPEED (LADEN/LIGHT)	←							DESIGN DATA							→	
192	VESSEL FACTORS DESIGN	MM	PROPELLER PITCH	←							DESIGN DATA							→	

Table 3-2
Diesel Engine Manufacturer/Licensee Recommended Practices

Slow Speed/Two Stroke Diesel Propulsion Plant

ITEM	SUB SYSTEM	MEASURED PARAMETER SYMBOL	MEASURED PARAMETER DESCRIPTION	ENGINE MFG/LICENSEE "A" SENSOR QTY	"A" SENSOR TYPE	"A" DISPLAY	ENGINE MFG/LICENSEE "B" SENSOR QTY	"B" SENSOR TYPE	"B" DISPLAY	ENGINE MFG/LICENSEE "C" SENSOR QTY	"C" SENSOR TYPE	"C" DISPLAY	ENGINE MFG/LICENSEE "D" SENSOR QTY	"D" SENSOR TYPE	"D" DISPLAY	ENGINE MFG/LICENSEE "E" SENSOR QTY	"E" SENSOR TYPE	"E" DISPLAY	REMARKS
193	VESSEL FACTORS - EXTERNAL	Ft/m	DRAFT (FWD & AFT)	2/SHIP	(6)	(6)	2/SHIP	(6)	(6)	2/SHIP	(6)	(6)	2/SHIP	(6)	(6)	2/SHIP	(6)	(6)	(6) VISI OR SPECIAL EQUIP
194																			
195		Knts	SPEED (BY LOG)	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	
196		Knts	SPEED (OVER GROUND)	←							OBSERVED							→	
197		Min.-1	RPM (SHAFT/ENGINE)	1/ENG	TGEN/RE	REMG	1/ENG	PP/TGEN	REMG	1/ENG	TGEN	REMG	1/ENG	TGEN	REMG	1/ENG	TGEN	REMG	
198		%	PROPELLER SLIP	NA	CALC	NA	NR	NR	NR	NA	CALC	NA	NA	CALC	NA	NR	NR	NR	
199																			
200		Ft/m	WATER DEPTH	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	
201		#	SEA STATE	←							OBSERVED							→	
202		DIR	SEA DIRECTION	←							OBSERVED							→	
203		#	WIND FORCE	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	
204		DIR	WIND DIRECTION	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	

4.0 ELECTRONIC SYSTEMS MANUFACTURERS RECOMMENDED PRACTICES

4.0 ELECTRONIC SYSTEM MANUFACTURERS RECOMMENDED PRACTICES

A technical survey of major European and Japanese electronic systems manufacturers who have supplied diagnostic systems to the marine diesel industry was conducted. This survey provided an opportunity to adequately assess the scope of the performance and condition monitoring equipment currently available today. The firms surveyed were in addition to the individual engine builders who manufactured and marketed their own performance and condition monitoring systems.

All manufacturers had previously supplied performance and condition monitoring systems for the slow speed, two stroke type of marine propulsion diesel. Three of the four system manufacturers had also provided equipment for medium speed, four stroke applications.

A detailed compilation of the Electronic Systems Manufacturers Recommended Practices is contained in Table 4-1, pages 4- 13 through 4-29.

The following sections also describe the various approaches each electronics manufacturer takes to support the diagnostic requirements of both the engine builders and the vessel operators.

4.1 Cylinder Combustion Processes

Three of the four electronics manufacturers offered uncooled, piezoelectric type transducers for sensing cylinder combustion pressures.

One manufacturer preferred to supply forced air cooling to its transducer with its standard installation. Figure 4-1 depicts and describes a typical air cooled, combustion pressure sensor arrangement.

Each manufacturer also offered different methods of data display, including various quantities of output information. Two of the four vendors calculated indicated horsepower (IHP), from the mean indicated pressures. One manufacturer also calculated and displayed heat release curves.

Generally, the methods of display can be divided into the following broad categories with various additional options available from each manufacturer:

* Digital Display only
* Digital Display with Oscilloscope
* Digital Display with Printer or Plotter
* CRT Display with Peripherals (e.g., Data Logger, Plotter, etc.)

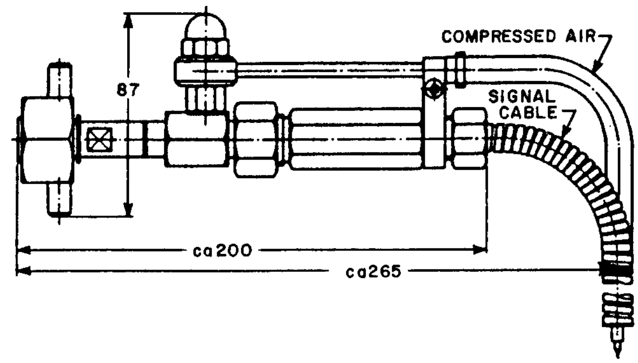
FIGURE 4-1

TYPICAL AIR COOLED COMBUSTION PRESSURE SENSOR
(REFERENCE 9)

The pressure transducer is of piezelectric type, and is supplied together with an amplifier which converts the small electric charge from the transducer to a voltage of 0 to 7.5 V, proportional to the pressure (150 kp/cm ^{2} give 7.5 V).

The transducer is made to fit on to the indicator cock, and is normally moved from cylinder to cylinder when measuring. One transducer is therefore enough. The transducer is cooled by compressed air.

The connection box should be located on a central place near the engine top. The transducer is connected to the amplifier by means of a cable, protected by flexible steel tube.



Various medium speed, four cycle monitoring techniques are also available. One manufacturer offers a portable, combustion pressure analyzer that can be utilized on either four stroke or two stroke engines with simply a change of coding plugs. Another manufacturer offers a peak pressure indicator with a P_{max} averaged over eight combustion cycles. A third manufacturer basically offers a scaled down version of their large system including MIP's and combustion pressures. Plotters, printers or oscilloscopes are available as options with any of the units.

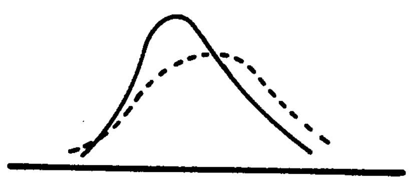
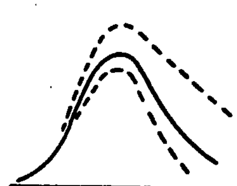
As discussed in Section 3.1.1, various technical and physical difficulties must be overcome when attempting to monitor the four cycle combustion process. These four cycle peculiarities result in unwanted pressure transients due to the physical placement of the combustion pressure transducers. Figure 4-2 describes some of these phenomena and the resulting difficulties.

As can be seen from Figure 4-2, the combustion pressure/time measurements for four stroke, medium and high speed diesels with long gas passages are influenced by certain external parameters. These constraints may require more elaborate correction techniques than simple sonic velocity offset factors.

See Table 4-1, Cylinder Combustion Processes, page 4-13 ,

FIGURE 4-2

MEDIUM SPEED COMBUSTION PRESSURE ANOMALIES DUE TO SAMPLING PATH CONFIGURATION (REFERENCE 10)

Item	Phenomenon	Characteristics	Problems
Free vibration in passage	 The free vibration in passage is superposed on the pressure waves.	The larger the passage diameter and shorter the passage length, the less is the vibration.	The presence of the vibration gives rise to considerable errors to the calculation of heat release.
Gain & phase	 The amplitude of the waves is damped while the phase is delayed.	Relations between the passage size (diameter and length) and gain's damping and phase's delay are similar to the above.	The gain's damping and the phase's delay are large obstacles in attaining the right combustion performance.
Thermal effect	 Since the difference in temperature between the two sides of the diaphragm causes the thermal stress in the diaphragm, i.e. actual pressure is affected.	The smaller the passage diameter and longer its length, the less is the thermal effect.	The calculation of the mean effective pressure becomes inaccurate.

for the details of the recommended practices for these parameters.

4.2 Fuel Injection Processes

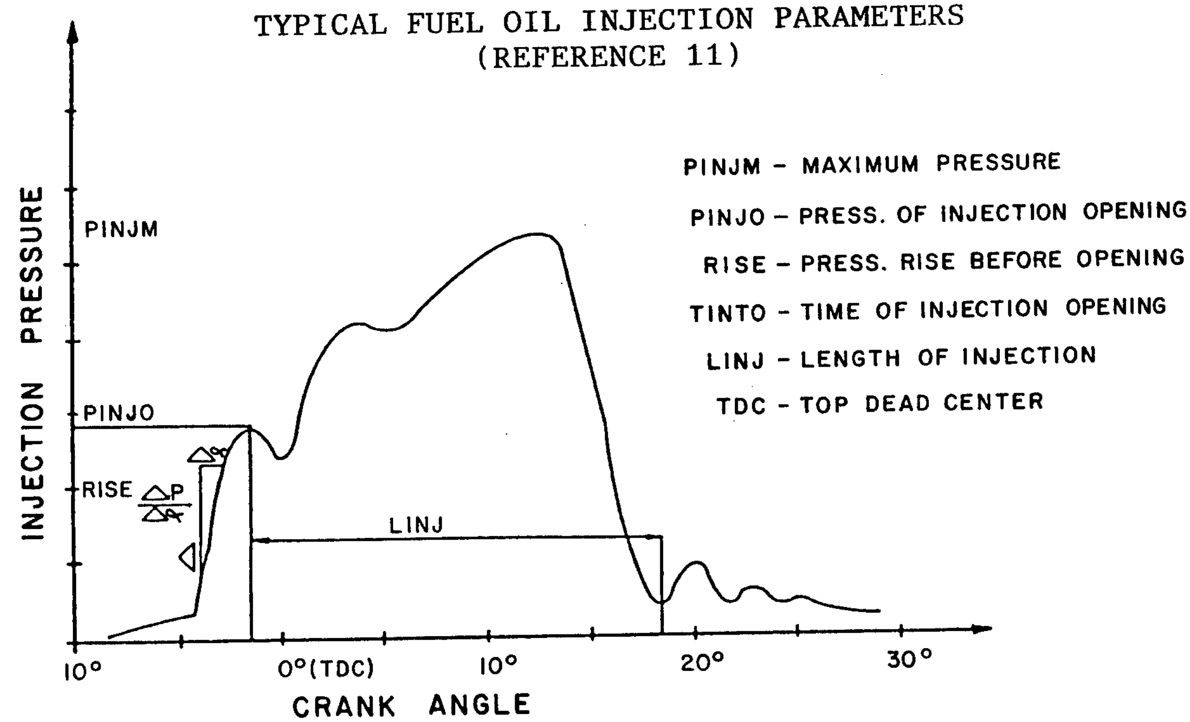
The monitoring of the high pressure fuel injection system is a somewhat controversial topic. Two of the four system vendors provide injection pressure sensing in their two stroke monitoring systems. Both of these vendors supply transducers of the uncooled piezoelectric type as shown in Figure 3-7, page 3-10.

One of these vendors felt strongly that injection monitoring is a necessity in the troubleshooting and isolation of slow speed fuel valve and fuel pump problems. The parameters shown in Figure 4-3 are typical of those monitored and displayed by this vendor.

The application of this technology to medium speed, four stroke engines is a different matter. All four of the manufacturers felt that although it is currently possible to monitor injection pressures, it is unlikely that this parameter would become an integral part of a four stroke, performance and diagnostic program. For the Recommended Practices of the Electronic Systems Manufacturers in this area refer to Table 4-1, Fuel Injection Processes, page 4-14.

FIGURE 4-3

TYPICAL FUEL OIL INJECTION PARAMETERS
(REFERENCE 11)



4.3 Air/Gas Processes

As previously mentioned, performance and condition monitoring of the scavenging air and exhaust gas path has been one of the most troublesome features to reliably implement.

Some of the earlier large, computer-based, trend oriented systems calculated numerous complex parameters for these subsystems such as:

* Air Flow
* Specific Air Consumption
* Compressor Efficiency
* Turbine Efficiency
* Pressure Drop through Engine
* Pressure Drop Air Side/Scavenging Air Cooler
* K Value/Scavenging Air Cooler

Much of this sophisticated numerical analysis was usually based on data from inaccurate and/or unstable sensors. After the first few negative experiences with the monitoring of these subsystems, the engineers gradually ignored the output and the system's credibility was lost forever.

All of the manufacturers surveyed felt that if high accuracy, low drift sensors were properly installed and maintained, the chances of success in monitoring these subsystems would be greatly enhanced.

No electronic systems manufacturer offered high speed electronic tachometers or vibration pick-ups of their own manufacture for turbocharger monitoring, but generally, they all recommended this equipment for both slow speed and medium speed engines.

Regarding valve monitoring, all of the manufacturers were aware of the difficulty in obtaining accurate exhaust valve temperatures. Some have experimented in conjunction with the engine builders by inserting temperature sensors near valve seats, etc. Basically the consensus is that no reliable economical system is available today to accurately measure valve face or seat temperatures.

See Table 4-1, Air and Gas Path Processes, pages 4-15 through 4-18 for a complete listing of the Electronic Manufacturers' Recommended Practices in this area.

4.4 Cylinder Components

Two of the four electronics manufacturers provide piston

ring condition monitoring and wear detection systems. A third electronics vendor offers an inductive sensor arrangement with an oscilloscope to monitor condition only. These systems are primarily manufactured for the slow speed, two stroke engines.

There also has been a certain amount of research and application engineering to date in this area for medium speed engines. The results have not been encouraging. The primary method of data acquisition has been to exploit the physical characteristics of the upper compression rings on these engines. These rings are usually plasma sprayed or chromium plated. When the coating wears off, the signal from the piston ring transducer is normally expected to change.

After much experimentation, the data has proven to be inconclusive. Uneven wear and unpredictable ring rotation have scattered the acquired data enough to make it less than useful.

All four of the electronic manufacturers offer cylinder liner temperature monitoring of one type or another. Three of the four vendors provide liner wear monitoring as an option. The general consensus is that these items are better suited technically and economically to the large, slow speed engines rather than the medium speed, four stroke units.

The Recommended Practices for Electronic System Manufacturers for Cylinder Components are contained in Table 4-1, pages 4-19 and 4-20.

4.5 Drive Train Bearing Components

The recommendations regarding bearing temperature monitoring primarily depend upon each manufacturer's experience in the past. All four vendors had provided Resistance Temperature Detecting (RTD) sensors in the oil return lines from each bearing on slow speed engines.

Figure 4-4 depicts a typical installation of this type of sensor in a medium speed engine.

Other novel techniques that have been utilized with some success on both slow speed and medium speed engines are depicted in Figures 4-5, (Wireless/Bearing Metal Temperature Thermistors), and 4-6, (Crankshaft Vertical Displacement Sensors), both shown on page 4-8.

For a complete listing of the parameters relating to this subject refer to Table 4-1, Drive Train Bearing Components, pages 4-23 through 4-24.

FIGURE 4-4

MEDIUM SPEED DIESEL
TYPICAL MAIN BEARING SHELL METAL TEMPERATURE RTD
(REFERENCE 12)

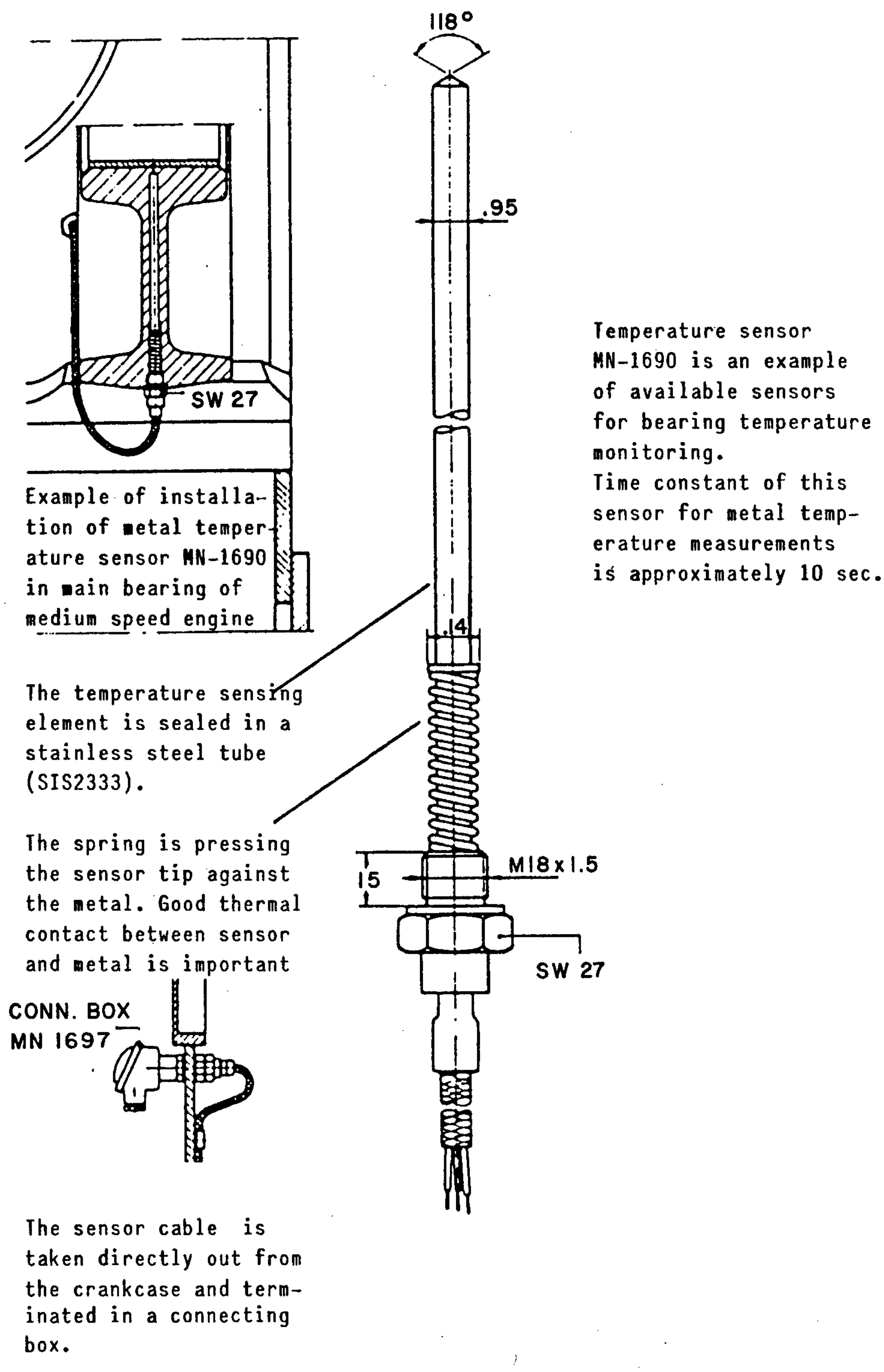


FIGURE 4-5

TYPICAL CRANKPIN BEARING WIRELESS/THERMISTOR
TEMPERATURE MONITORING
(REFERENCE 13)

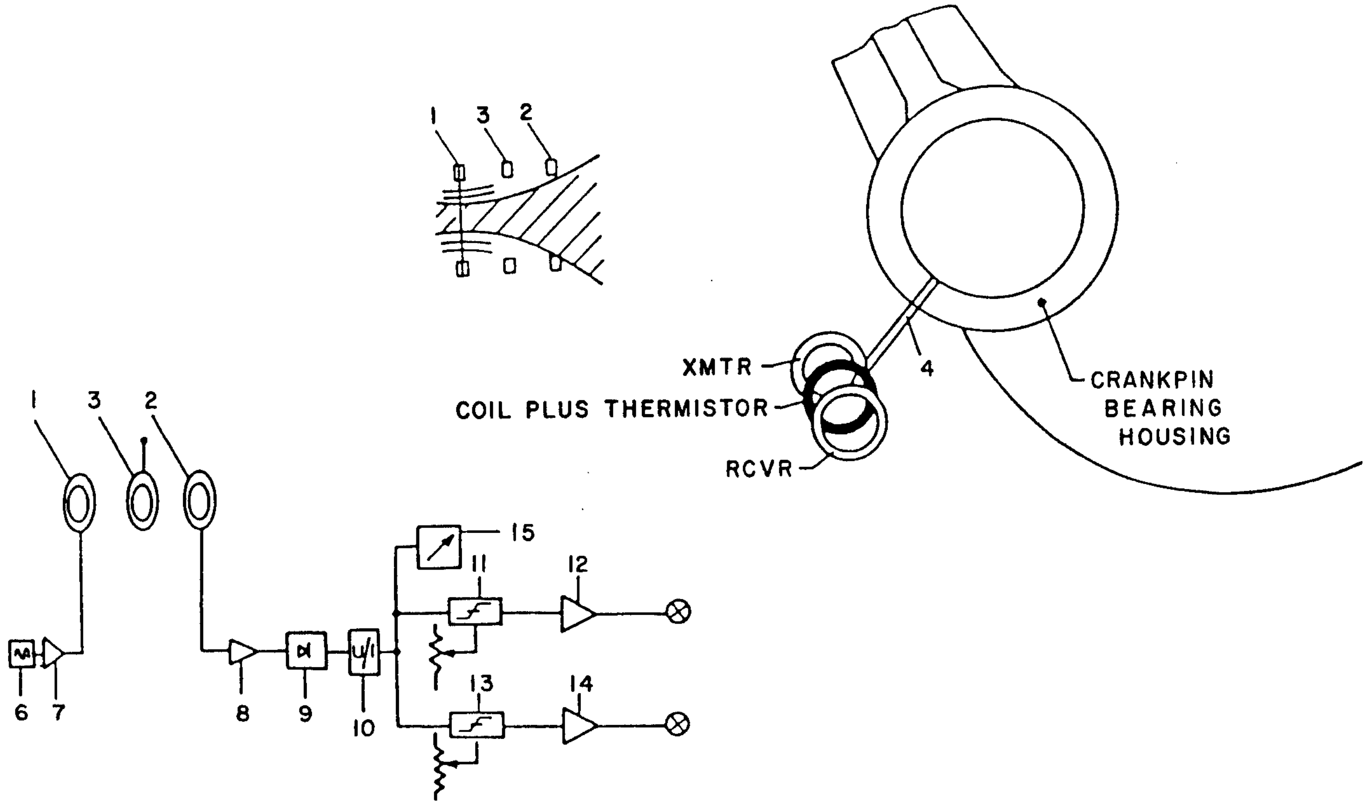
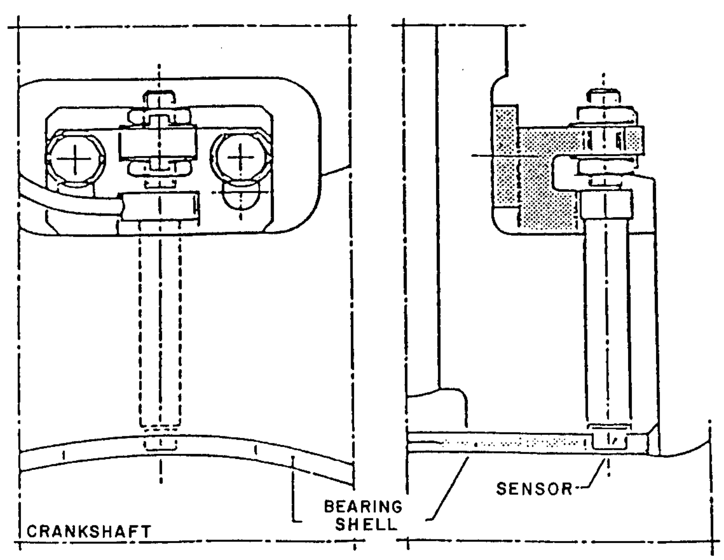


FIGURE 4-6

TYPICAL CRANKSHAFT BEARING SHELL DISPLACEMENT TRANSDUCER
(REFERENCE 14)



4.6 Heat Exchanger Components

All four of the electronic systems manufacturers recommended that the main and auxiliary heat exchangers be monitored by RTD's. Three of the four had made provision for entering this type of data into their system in order to calculate cooler efficiencies and plot trend lines. See Table 4-1, Heat Exchanger Components, page 4-25 through 4-26 for details.

4.7 Data Processing, Utilization and Display

There is a wide variety of available systems from each of the four electronics manufacturers. There are significant differences in each vendor's approach and individual philosophy.

Two of the systems vendors initially offered, in the mid-70's, large centralized systems with elaborate predictive and diagnostic features. They now recommend much smaller, "dedicated" type subsystems, tailored to individual problems. One vendor displays a certain amount of system deviation information while another manufacturer only displays raw data. These systems are offered for both slow speed and medium speed engines.

The third manufacturer has taken the modularized "building block" type of approach from the start. Specific subsystems for MIP calculations, piston ring monitoring, thermal load monitoring and injection pressure sensing are offered. No predictive or performance deviation type parameters are displayed or utilized. Portions of the above systems are only applicable to slow speed engines while other segments are geared towards the four stroke units.

The final manufacturer recommends a large, color CRT based, diagnostic and predictive type of onboard system. This system utilizes advanced color graphics and trend line predictions. It is primarily intended for the slow speed two stroke high horsepower engines.

4.8 Use of Tables

Table 4-1 provides a summary of the electronic manufacturers' recommended practices for diagnostic equipment on both slow and medium speed diesel propulsion plants. The individual recommendations within the table are applicable to both types of engines except where noted in the remarks column.

This compilation of information is based on the availability of equipment from each manufacturer, tempered by their individual suggestions. If the vendor was able to supply the particular monitoring function, he then usually recommended it.

The table is arranged by subsystem, paralleling the text sequence of Section 4.0.

FIGURE 4-7

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 4-1

Abbreviations/ Symbols	Descriptions	Abbreviations/ Symbols	Description
ABS	Absolute	HTR	Heater
AN	Anemometer	HYGR	Hygrometer
APPT	Air Cooled Piezo-electric Pressure Transducer	IHP	Indicated Horsepower
BHP	Brake Horsepower	ISEN	Inductive Sensor
BLR	Boiler	LOG	Manually Log
BRG	Bearing	MAN	Manometer
CALC	Calculated	MIP	Mean Indicated Pressure
CATC	Chromel-Alumel Thermocouple	MIT	Manual Input For Trend
CLR	Cooler	NA	Not Applicable
CRT	Cathode Ray Tube	NAV	Not Available
CVR	Cover	NCTC	Ni Cr/Ni Thermocouple
CYL	Cylinder	NR	Not Required
DIG	Ditigal Display	OPT	Optional
DL	Data Logger	OSC	Oscilliscope
DSDR	Depth Sounder	PL	Plotter
EM	Electronic Monitor	PO	Print Out
ER	Engine Room	POTT	Potentiometric Transducer
ENG	Engine	PP	Proximity Probe
FM	Flow Meter	PMP	Pump
FLTR	Filter		
HR	Heat Release		

FIGURE 4-7

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 4-1 CONTINUED

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Descripton
PRB	Probe	90 PPR	Ninety Pins Per Revolution
PT	Pressure Transducer	Δ	Differential
RE	Rotary Encoder	+	and
RTD	Resistance Temperature Detector	/	or
SSD	Slow Speed Diesel Only	REMG	Remote Gauge or Indicator
SEP	Separator	LOCG	Local Gauge or Indicator
SPC	Speed Power Curve	VISI	Visual Inspection
STK	Stack	VISM	Viscometer
SYNT	Synchronous Transmitter		
T/C	Turbocharger		
TFR	Thin Film Resistor		
TG	Temperature Gauge		
TGEN	Tachometer Generator		
TPP	Telescopic Pipe Probe		
TURB	Turbine		
UPPT	Uncooled Piezoelectric Pressure Transducer		
ULSON	Ultrasonic		
30 PPR	Thirty Pins Per Revolution		

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
1	CYLINDER COMBUSTION PROCESSES	P mi or MIP	MEAN INDICATED PRESSURE (per cylinder)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	APPT	OSC + DIG	1/ENG	UPPT	CRT/ DIG+PL	1/ENG	UPPT	CRT & DL	(1) SINGLE COMMON SENSOR FOR ALL PARAM.
2																
3		P_{max}	MAXIMUM OR FIRING PRESSURE (per cylinder) (1)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	APPT	OSC + DIG	1/ENG	UPPT	CRT/ PL+DIG	1/ENG	UPPT	CRT/ DL	
4		P_{comp}	COMPRESSION PRESSURE (per cylinder) (1)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	APPT	OSC + DIG	1/ENG	UPPT	CRT/ PL+DIG	1/ENG	UPPT	CRT/ DL	
5		P_{exp}	EXPANSION PRESSURE (per cylinder) (1)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	APPT	OSC + DIG	1/ENG	UPPT	CRT/ PL+DIG	1/ENG	UPPT	CRT/ DL	
6																
7		$\propto P_{max}$	ANGLE OR TIME OF P_{max} (per cylinder)	1/ENG	90 PPR & PP	CRT/ PO+DIG	1/ENG	30 PPR & PP	OSC + DIG	1/CYL	TPP	CRT/ PL+DIG	1/ENG	RE	CRT & DL	
8		$\propto P_{comp}$	ANGLE OR TIME OF P_{comp} (per cylinder)	1/ENG	90 PPR & PP	CRT/ PO+DIG	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
9																
10		RPM	SPEED AT ENGINE FLYWHEEL	1/ENG	90 PPR & PP	CRT/ PO+DIG	1/ENG	30 PPR & PP	DIG	1/ENG	TGEN	CRT/ DIG	1/ENG	TGEN	CRT & DL	
11		T/BHP	TORQUE/BHP AT ENGINE (value, method and location)	1/ENG	MIP & IHP	CRT/ PO+DIG	1/ENG	MIP	DIG	1/ENG	BHP + MIP	CRT/ DIG	1/ENG	BHP,IHP SPC,MIP HR	CRT & DL	
12		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ENG	PT	CRT/ PO+DIG	1/ENG	PT	DIG	1/ENG	PT	CRT/ DIG	1/ENG	PT	CRT & DL	

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
13	FUEL OIL INJECTION PROCESSES	POS & % DROOP	FUEL GOVERNOR POSITION AND SPEED DROOP	NA	MIT	NA	NR	NR	NR	NA	MIT (OPT)	NA	1/ENG	SYNT	REMG	
14		INDEX	FUEL PUMP INDEX (per cylinder)	NA	MIT	NA	NR	NR	NR	1/PMP	POTT	REMG	NR	NR	NR	
15																
16		T cyl cover	CYLINDER TOP COVER TEMPS (per cylinder)	1/CVR	CATC	CRT/ PO+DIG	1/CVR	CATC	DIG	1/CVR	CATC	CRT/ DIG	1/CVR (OPT)	CATC (OPT)	CRT (OPT)	
17		P_{rise}	PRESSURE RISE PRIOR TO OPENING OF INJ VLV (per cylinder)	1/ENG	UPPT	CRT/ PO+DIG	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
18		P_{injo}	DYNAMIC OPENING PRESS OF INJ VLV (per cylinder)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	UPPT	DIG	NAV	NAV	NAV	NAV	NAV	NAV	
19		P_{injo}	MAXIMUM INJECTION PRESSURE (per cylinder)	1/ENG	UPPT	CRT/ PO+DIG	1/ENG	UPPT	DIG	NAV	NAV	NAV	NAV	NAV	NAV	
20																
21		T_{injo}	TIME OF OPENING OF INJECTION VLV (per cylinder)	1/ENG	UPPT 90 PPR PP	CRT/ PO+DIG	1/ENG	UPPT + 30 PPR PP	DIG	NAV	NAV	NAV	NAV	NAV	NAV	
22		L_{injo}	LENGTH OF OPENING OF INJECTION VLV (per cylinder)	1/ENG	UPPT 90 PPR PP	CRT/ PO+DIG	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
23																
24																

Table 4-1
Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
25	AIR & GAS PATH PROCESSES															
26		P_{baro}	ENGINE ROOM BAROMETRIC PRESSURE	1/ER	MAN	LOGG	1/ER	MAN	LOGG	1/ER	MAN	LOGG	1/ER	MAN	LOGG	
27																
28		$T_{E.R.}$	ENGINE ROOM AMBIENT TEMPERATURE	1/ER	TG	LOGG	1/ER	TG	LOGG	1/ER	TG	LOGG	1/ER	TG	LOGG	
29																
30		H_{rel}	ENGINE ROOM RELATIVE HUMIDITY	1/ER	HYGR	LOGG	1/ER	HYGR	LOGG	1/ER	HYGR	LOGG	1/ER	HYGR	LOGG	
31																
32		ΔP_{air}	AIR PRESSURE DROP ACROSS T/C SCAV INLET FILTER (per T/C)	1 per T/C	ΔPT	CRT/DIG	1 per T/C	ΔPT	REMG	1 per T/C	ΔPT	CRT/DIG	1 per T/C	ΔPT	CRT & DL	
33																
34		Pcomp inlet	T/C COMPRESSOR INLET SUCTION PRESSURE (per T/C)	1 per T/C	ABS PT	CRT/DIG	1 per T/C	ABS PT	REMG	1 per T/C	ABS PT	CRT/DIG	NR	NR	NR	
35		ΔP_{TC}	AIR PRESSURE DROP ACROSS T/C COMPRESSOR HOUSING (per T/C)	1 per T/C	ΔPT	CRT/DIG	1 per T/C	ΔPT	REMG	1 per T/C	ΔPT	CRT/DIG	NR	NR	NR	
36		Pcomp outlet	AIR PRESSURE AFTER T/C COMPRESSOR (per T/C)	1 per T/C	PT	CRT/DIG	1 per T/C	PT	REMG	1 per T/C	PT	CRT/DIG	1/TC	PT	CRT & DL	

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
37	AIR & GAS PATH PROCESSES	$P_{sw\ in}$	SEA WATER PRESSURE AT INLET TO COOLER	1/CLR	PT	REMG	1/CLR	PT	REMG	1/CLR	PT	REMG	1/CLR	PT	REMG	
38																
39		ΔP_{air}	AIR PRESSURE DROP ACROSS CHARGE AIR COOLER (per cooler)	1/CLR	Δ PT	DIG/ CRT	1/CLR	Δ PT	REMG	1/CLR	Δ PT	DIG/ CRT	1/CLR	Δ PT	CRT & DL	
40		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ENG	PT	DIG/ CRT	1/ENG	PT	REMG	1/ENG	PT	DIG/ CRT	1/ENG	PT	CRT & DL	
41																
42		Pturb inlet	EXHAUST GAS PRESSURE BEFORE TURBINE (per T/C)	1 per T/C	PT	DIG/ CRT	1 per T/C	PT	REMG	1 per T/C	PT	DIG/ CRT	NR	NR	NR	
43		Pturb outlet	EXHAUST GAS PRESSURE AFTER TURBINE (per T/C)	1 per T/C	PT	DIG/ CRT	1 per T/C	PT	REMG	1 per T/C	PT	DIG/ CRT	NR	NR	NR	
44																
45		P into boiler	EXHAUST GAS PRESSURE BEFORE WASTE HEAT BOILER	1/BLR	PT	DIG/ CRT	1/BLR	PT	REMG	1/BLR	PT	DIG/ CRT	NR	NR	NR	
46		P_{out}	EXHAUST GAS PRESSURE AFTER WASTE HEAT BOILER	1/BLR	PT	DIG/ CRT	1/BLR	PT	REMG	1/BLR	PT	DIG/ CRT	NR	NR	NR	
47		% CO_2	EXHAUST GAS PERCENT CO_2	NAV	NAV	DIG/ NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
48		—	EXHAUST GAS CONDITION (opacity, etc)	NR	VISI	DIG/ NR	NR	VISI	NR	1/STK	EM	REMG	NR	VISI	NR	

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
49	AIR & GAS PATH PROCESSES	T air in comp	AIR TEMP AT INLET TO T/C COMPRESSOR (per T/C)	1 per T/C	RTD	CRT/ DIG	1 per T/C	RTD	REMG	1 per T/C	RTD	CRT/ DIG	1 per T/C	RTD	CRT & DL	
50		T air out comp	AIR TEMP AT OUTLET OF T/C COMPRESSOR (per T/C)	1 per T/C	RTD	CRT/ DIG	1 per T/C	RTD	REMG	1 per T/C	RTD	CRT/ DIG	1 per T/C	RTD	CRT & DL	
51																
52		T air in cool	AIR TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	REMG	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	CRT & DL	
53		T air outcool	AIR TEMP AT OUTLET OF CHARGE AIR COOLER (per cooler)	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	REMG	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	CRT & DL	
54																
55		T sw in cool	SEA WATER TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	REMG	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	CRT & DL	
56		T sw outcool	SEA WATER TEMP AT OUTLET FROM CHARGE AIR COOLER (per cooler)	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	REMG	1/CLR	RTD	CRT/ DIG	1/CLR	RTD	CRT & DL	
57																
58		T_{scav}	SCAVENGING BELT AIR TEMPERATURE	1/ENG	RTD	CRT/ DIG	1/ENG	RTD	REMG	1/ENG	RTD	CRT/ DIG	1/ENG	RTD	CRT & DL	
59																
60																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
61	AIR & GAS PATH PROCESSES	T exh indiv.	EXHAUST GAS TEMP AFTER CYLINDERS (individual)	1/CYL	NCTC	CRT/ DIG	1/CYL	NCTC	REMG	1/CYL	NCTC	CRT/ DIG	1/CYL	RTD	CRT & DL	
62		T exh mean	EXHAUST GAS TEMP AFTER CYLINDER (mean)	NA	CALC	CRT/ DIG	NA	CALC	REMG	NA	CALC	CRT/ DIG	NA	CALC	CRT & DL	
63		T exh dev.	EXHAUST GAS TEMP AFTER CYLINDERS (max. deviation)	NA	CALC	CRT/ DIG	NA	CALC	REMG	NA	CALC	CRT/ DIG	NA	CALC	CRT & DL	
64																
65		T exh to turb	EXHAUST GAS TEMP BEFORE TURBINE (per T/C)	1 per T/C	NCTC	CRT/ DIG	1 per T/C	NCTC	REMG	1 per T/C	NCTC	CRT/ DIG	1 per T/C	RTD	CRT & DL	
66		T exh out turb	EXHAUST GAS TEMP AFTER TURBINE (per T/C)	1 per T/C	NCTC	CRT/ DIG	1 per T/C	NCTC	REMG	1 per T/C	NCTC	CRT/ DIG	1 per T/C	RTD	CRT & DL	
67		T_{in}	EXHAUST GAS TEMP BEFORE WASTE HEAT BOILER	1/BLR	TC	CRT/ DIG	1/BLR	TC	REMG	1/BLR	TC	CRT/ DIG	1/BLR	RTD	CRT & DL	
68		T_{out}	EXHAUST GAS TEMP AFTER WASTE HEAT BOILER	1/BLR	TC	CRT/ DIG	1/BLR	TC	REMG	1/BLR	TC	CRT/ DIG	1/BLR	RTD	CRT & DL	
69		η_{turb}	TURBOCHARGER TURBINE EFFICIENCY	NA	CALC	CRT/ DIG	NAV	NAV	NAV	NA	CALC (OPT)	CRT/ DIG	NA	CALC	CRT & DL	
70		η_{compr}	TURBOCHARGER COMPRESSOR EFFICIENCY	NA	CALC	CRT/ DIG	NAV	NAV	NAV	NA	CALC (OPT)	CRT/ DIG	NA	CALC	CRT & DL	
71		η_{TC}	TURBOCHARGER OVERALL EFFICIENCY	NA	CALC	CRT/ DIG	NAV	NAV	NAV	NA	CALC (OPT)	CRT/ DIG	NA	CALC	CRT & DL	
72																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
73	CYLINDER COMPONENTS (RINGS)	—	PISTON RING COLLAPSE (2)	2/CYL	ISEN	CRT/ PO	2/CYL	ISEN	OSC	NAV	NAV	NAV	1/CYL	ISEN (OPT)	CRT (OPT)	(2) COMMON SENSOR ALL PARAMETERS
74		—	PISTON RING BREAKAGE (2)	2/CYL	ISEN	CRT/ PO	2/CYL	ISEN	OSC	NAV	NAV	NAV	1/CYL	ISEN (OPT)	CRT (OPT)	NOTE: ITEMS 73–78 SSD
75		—	PISTON RING STICKING (2)	2/CYL	ISEN	CRT/ PO	2/CYL	ISEN	OSC	NAV	NAV	NAV	1/CYL	ISEN (OPT)	CRT (OPT)	
76		MM	PISTON RING WEAR (2)	2/CYL	ISEN	CRT/ PO	NAV	NAV	NAV	NAV	NAV	NAV	1/CYL	ISEN (OPT)	CRT (OPT)	
77																
78		HRS	PISTON RING OPERATING HRS	NA	MIT (OPT)	CRT/ PO	NAV	NAV	NAV	NA	MIT (OPT)	CRT (OPT)	NA	MIT	CRT	
79	CYLINDER COMPONENTS (PISTONS)	MM	PISTON GROOVE CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
80		MM	PISTON GROOVE WEAR	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
81		—	PISTON CROWN CONDITION	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
82		MM	PISTON CROWN WEAR	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	NA	VISI	NA	
83																
84		HRS	PISTON OPERATING HOURS	NA	MIT (OPT)	CRT/ PO	NAV	NAV	NAV	NA	MIT (OPT)	CRT (OPT)	NA	MIT	CRT	

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
85	CYLINDER COMPONENTS - LINERS	TLiner (upper)	CYLINDER LINER TEMPERATURE (upper) (blow-by)	2/CYL	CATC	CRT/ PO	2/CYL	CATC	DIG	2/CYL	CATC (OPT)	CRT (OPT)	4/CYL	CATC	CRT & DL	NOTE: ITEMS 85-92 SSD
86																
87		TLiner (lower)	CYLINDER LINER TEMP (lower) (skirt seizures)	(OPT)	TC (OPT)	CRT (OPT)	(OPT)	TC (OPT)	DIG (OPT)	4/CYL	CALC (OPT)	CRT (OPT)	1/CYL	CATC	CRT & DL	
88		T_{scuff}	CYLINDER LINER TEMP (scuffing) (micro seizures)	(OPT)	TC (OPT)	CRT (OPT)	1/CYL	CATC	DIG	4/CYL	CALC (OPT)	CRT (OPT)	1/CYL	CATC	CRT & DL	
89																
90		——	CYLINDER LINER CONDITION (trend)	2/CYL	I SEN & TC	CRT	NAV	NAV	NAV	OPT	TC (OPT)	CRT (OPT)	5/CYL	TC	CRT & DL	
91		MM	CLYLINDER LINER WEAR	1/CYL	TFR (OPT)	CRT (OPT)	NAV	NAV	NAV	1/CYL	TFR (OPT)	CRT (OPT)	1/CYL	TFR (OPT)	CRT & DL(OPT)	
92		HRS	CYLINDER LINER OPERATING HOURS	NA	MIT	CRT	NA	NA	LOG	NA	MIT (OPT)	CRT (OPT)	NA	MIT	CRT & DL	
93																
94		Kg/Day	CYLINDER LINER LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	MIT (OPT)	CRT (OPT)	NA	NA	LOG	
95		Kg/Day	ENGINE LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	NA	MIT (OPT)	CRT (OPT)	NA	NA	LOG	
96																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
97	AIR/GAS PATH COMPONENTS (TURBOCHARGERS)	RPM	TURBOCHARGER SPEED (per T/C)	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
98		MILS	TURBOCHARGER VIBRATION LEVEL (per T/C)	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
99																
100		$T_{LO\ in}$	TURBOCHARGER LUBE OIL INLET TEMP (per T/C)	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	
101		$T_{LO\ out}$	TURBOCHARGER LUBE OIL OUTLET TEMP (per T/C)	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	1 per T/C	RTD	REMG	
102		$P_{LO\ in}$	TURBOCHARGER LUBE OIL INLET PRESSURE (per T/C)	1 per T/C	PT	REMG	1 per T/C	PT	REMG	1 per T/C	PT	REMG	1 per T/C	PT	REMG	
103																
104	AIR/GAS PATH COMPONENTS (EXH. VLV)	MM	SPINDLE GUIDE CLEARANCE	← NOT APPLICABLE →												
105		MM	RING CLEARANCE	← NOT APPLICABLE →												
106		MM	SPINDLE WEAR	← NOT APPLICABLE →												
107		MM	SEAT WEAR	← NOT APPLICABLE →												
108																

Table 4-1
Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
109	AIR/GAS PATH COMPNENTS (EXHAUST VALVES)	—	SEAT BURNING	← NOT APPLICABLE →												
110		—	SPRING CONDITION	← NOT APPLICABLE →												
111																
112		MM	HYDRAULIC LINER DIAMETER	← NOT APPLICABLE →												
113		MM	ROLLER CLEARANCES	← NOT APPLICABLE →												
114		—	CAM & ROLLER SURFACES	← NOT APPLICABLE →												
115		—	HOUSING & GUIDE SURFACES	← NOT APPLICABLE →												
116																
117		HRS	OPERATING HOURS	← NOT APPLICABLE →												
118																
119																
120																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
121	DRIVE TRAIN BEARING COMPONENTS	T oil out	MAIN BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	
122		T_{brg}	MAIN BEARING HOUSING & SHELL TEMPERATURE	NAV	NAV	NAV	1/BRG	RTD (OPT)	REMG	NAV	NAV	NAV	NAV	NAV	NAV	
123		MM	MAIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →												
124																
125		T oil out	CRANK PIN BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	
126		T_{brg}	CRANK PIN BEARING HOUSING & SHELL TEMPERATURES	NAV	NAV	NAV	1/BRG	RTD (OPT)	REMG	NAV	NAV	NAV	NAV	NAV	NAV	
127		MM	CRANK PIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →												
128																
129		T oil out	CROSSHEAD BEARING OIL OUTLET TEMPERATURES	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	NOTE: ITEMS 129-131 SSD
130		T_{brg}	CROSSHEAD BEARING HOUSING TEMPERATURE	NAV	NAV	NAV	1/BRG	RTD (OPT)	REMG	NAV	NAV	NAV	NAV	NAV	NAV	
131		MM	CROSSHEAD BEARING CLEARANCES	← MANUAL MEASUREMENTS →												
132																

Table 4-1
Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
133	DRIVE TRAIN BEARING COMPONENTS	T oil out	THRUST BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	1/BRG	RTD	REMG	
134		T_{brg}	THRUST BEARING PAD METAL TEMPERATURE	NAV	NAV	NAV	1/BRG	RTD (OPT)	REMG	NAV	NAV	NAV	NAV	NAV	NAV	
135		MM	THRUST BEARING PAD CLEARANCES	← MANUAL MEASUREMENTS →												
136		MM	CAMSHAFT BEARING CLEARANCES													
137		PPM	CRANKCASE OIL MIST DETECTION	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	
138		MM	CONTROL DRIVE GEAR BACKLASH													
139		—	LUBE OIL ANALYSIS (ferrography, etc.)	NA	LAB ANALY	NA	NA	LAB ANALY	NA	NA	LAB ANALY	NA	NA	LAB ANALY	NA	
140																
141		MM	CRANKSHAFT MAIN BEARING DISPLACEMENT	← MANUAL MEASUREMENTS →												
142																
143		MM	CRANKWEB DEFLECTION ANALYSIS	← MANUAL MEASUREMENTS →												
144																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
145	HEAT EXCHANGER COMPONENTS - MAIN	$\Delta T_{F.W.}$	JACKET WATER F.W. TEMP ACROSS JACKET WATER COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
146		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS JACKET WATER COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
147																
148		$\Delta T_{F.W.}$	PISTON COOLING F.W. TEMP ACROSS PISTON COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	NOTE: ITEMS 148-149 SSD
149		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS PISTON COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
150																
151		$\Delta T_{L.O.}$	MAIN LUBE OIL TEMP ACROSS LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
152		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
153																
154		$\Delta T_{L.O.}$	TURBOCHARGER LUBE OIL TEMP ACROSS T/C LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
155		$\Delta T_{S.W.}$	SALT WATER TEMP ACROSS T/C LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	CRT & DL	
156																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
				SENSOR			SENSOR			SENSOR			SENSOR			
		SYMBOL	DESCRIPTION	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	
157	HEAT EXCHANGER COMPONENTS-MAIN	$\Delta T_{L.O}$	CAMSHAFT LUBE OIL TEMP ACROSS CAMSHAFT L.O. COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	NOTE: ITEMS 157-158 SSD
158		$\Delta T_{S.W}$	SALT WATER TEMP ACROSS CAMSHAFT L.O. COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
159																
160		—	FRESH WATER COOLING ADDITIVE ADEQUACY	← MANUAL WATER ANALYSIS →												PH & SALINITY
161	HEAT EXCHANGER COMPONENTS AUXILIARY	$\Delta T_{F.W}$	AUX ENG CYL FRESH WATER TEMP ACROSS COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
162		$\Delta T_{S.W}$	SALT WATER TEMP ACROSS FRESH WATER COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
163																
164		ΔT_{air}	AUX ENG CHARGE AIR TEMP ACROSS CHARGE AIR COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
165		$\Delta T_{S.W}$	SALT WATER TEMP ACROSS CHARGE AIR COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
166																
167		$\Delta T_{L.O}$	AUX ENG LUBE OIL TEMP ACROSS LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	
168		$\Delta T_{S.W}$	SALT WATER TEMP ACROSS LUBE OIL COOLER	2/CLR	RTD	CRT/ DIG	2/CLR	RTD	REMG	2/CLR	RTD	CRT	2/CLR	RTD	CRT & DL	

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
169	FUEL OIL DELIVERY COMPONENTS	$T_{F.O.W.}$	FUEL OIL TEMP BEFORE PREHEATERS	1/HTR	RTD	REMG	1/HTR	RTD	REMG	1/HTR	RTD	REMG	1/HTR	RTD	REMG	
170		T F.O. visc.	FUEL OIL TEMP AFTER PREHEATERS AT VISCOMETER	1/VIS	RTD	REMG	1/VIS	RTD	REMG	1/VIS	RTD	REMG	1/VIS	RTD	REMG	
171		T F.O. in	FUEL OIL TEMP AT ENGINE INLET	1/ENG	RTD	REMG	1/ENG	RTD	REMG	1/ENG	RTD	REMG	1/ENG	RTD	REMG	
172																
173		P in fltr	FUEL OIL PRESSURE BEFORE FILTERS	1/FLTR	PT	REMG	1/FLTR	PT	REMG	1/FLTR	PT	REMG	1/FLTR	PT	REMG	
174		P out fltr	FUEL OIL PRESSURE AFTER FILTERS AT ENGINE INLET	1/FLTR	PT	REMG	1/FLTR	PT	REMG	1/FLTR	PT	REMG	1/FLTR	PT	REMG	
175																
176		Q F.O.	FUEL OIL CONSUMPTION/ FLOW RATE	1/ENG	TURB FM	CRT/ DIG	NAV	NAV	NAV	1/ENG	ULSON FM	REMG	NAV	NAV	NAV	
177																
178		T in sep.	FUEL OIL TEMPERATURE BEFORE SEPARATOR	1/SEP	RTD	REMG	1/SEP	RTD	REMG	1/SEP	RTD	REMG	1/SEP	RTD	REMG	
179		Q % flow	FUEL OIL PERCENT THROUGHPUT AT SEPARATORS	1/SEP	FM	REMG	1/SEP	FM	REMG	1/SEP	FM	REMG	1/SEP	FM	REMG	
180																

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		QTY	TYPE		QTY	TYPE		
181	FUEL OIL DELIVERY COMPONENTS	cSt	FUEL OIL VISCOSITY AT 50°C	← LAB ANALYSIS →												
182		S.G/ρ	FUEL OIL SPECIFIC GRAVITY OR DENSITY	← LAB ANALYSIS →												
183		%S	FUEL OIL SULFUR CONTENT	← LAB ANALYSIS →												
184		%V	FUEL OIL VANADIUM CONTENT	← LAB ANALYSIS →												
185		h_i	FUEL OIL HEATING VALUE	← LAB ANALYSIS →												
186																
187	VESSEL FACTOR DESIGN	Ft/m	DRAFT (FWD/AFT) BALLAST	← DESIGN DATA →												
188		Ft or m	DRAFT (FWD/AFT) LADEN	← DESIGN DATA →												
189		DWT	DEADWEIGHT/BALLAST	← DESIGN DATA →												
190		DWT	DEADWEIGHT/LADEN	← DESIGN DATA →												
191		Knts	SPEED (LADEN/LIGHT)	← DESIGN DATA →												
192		MM	PROPELLER PITCH	← DESIGN DATA →												

Table 4-1

Electronic Systems Manufacturers Recommended Practices

Marine Two and Four Stroke Diesel Propulsion Plants

ITEM	SUB SYSTEM	MEASURED PARAMETER		ELECTRONICS MANUFACTURER "A"			ELECTRONICS MANUFACTURER "B"			ELECTRONICS MANUFACTURER "C"			ELECTRONICS MANUFACTURER "D"			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
193	VESSEL FACTORS - EXTERNAL	Ft/m	DRAFT (FWD & AFT)	2/SHIP	(3)	(3)	2/SHIP	(3)	(3)	2/SHIP	(3)	(3)	2/SHIP	(3)	(3)	(3) VISUAL OR SPEC. EQUIP.
194																
195		KNTS	SPEED (BY LOG)	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	1/SHIP	SPLG	REMG	
196		KNTS	SPEED (OVER GROUND)	OBSERVED												
197		Min.-1	RPM (SHAFT/ENGINE)	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	1/SHFT	TGEN	REMG	
198		%	PROPELLER SLIP	NA	CALC	NA	NA	CALC	NA	NA	CALC	NA	NA	CALC	NA	
199																
200		Ft/m	WATER DEPTH	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	1/SHIP	DSDR	REMG	
201		#	SEA STATE	OBSERVED												
202		DIR	SEA DIRECTION	OBSERVED												
203		#	WIND FORCE	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	
204		DIR	WIND DIRECTION	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	1/SHIP	AN	REMG	

5.0 CLASSIFICATION SOCIETY REQUIREMENTS

5.0 CLASSIFICATION SOCIETY REQUIREMENTS

Since the classification societies generally affect a significant portion of the operating and design segments of the maritime communities, one of the survey's first objectives was to thoroughly review the currently published rules of the major societies regarding diesel performance and condition monitoring.

Subsequent to this, five major European and Japanese classification societies were interviewed at length in their home offices with their in-house technical staffs.

5.1 Current Guidelines

After reviewing the current published regulations, it became apparent that although a substantial amount of explicit guidance exists regarding automation in general, very little has been published concerning diesel plant diagnostics, per se.

Three societies made no specific mention of performance monitoring or condition monitoring systems while the two remaining societies addressed the subject only in the light of their survey requirements. The following excerpts highlight the areas which are explicitly detailed in the applicable rules.

* Det Norske Veritas Rules - Part 1, Chapter 2, Sect. 2, B103 - Special Periodical Survey - Machinery and Electrical Equipment:

  "For machinery equipped with instruments making it possible to ascertain the condition of the machinery components, special approval may be made as to the extent and method of the survey."

* Lloyd's Register - Chapter 2, Part 1, 3.5.21:

  "Where condition monitoring equipment is fitted, the Committee, upon application by the Owner, will be prepared to amend applicable periodical survey requirements, where details of the equipment are submitted and found satisfactory. Where machinery installations are accepted for this method of survey, it will be a requirement that an Annual Survey be held, at which time monitored records will be analyzed and the machinery examined under working conditions."

It should be noted that many of the "general" guidelines published concerning automation design, hardware, limitations, etc. would of course implicitly apply to any shipboard condition monitoring system, although it must be remembered that the only "explicit" references to diagnostics are represented by the two previous rule extracts.

The three societies that had not published any explicit guide-

lines on condition or performance monitoring held more or less similar views. Their central theme was that, regarding survey modifications, the entire ship (i.e. hull, machinery, maintenance systems, crew, etc.) would be assessed on an individual case-by-case basis. Each society declared that they would (to varying degrees), be receptive to a broad range of well conceived, repeatable, and reliable data based monitoring systems.

The two societies that had published modifications to their rules to accommodate condition monitoring were slightly more formal in their approach to the acceptance of condition monitoring based systems. Neither society would accept performance monitoring or condition monitoring by itself as a replacement for class internal surveys. Generally, these societies would consider a multi-disciplined approach to determine if the equipment in question is:

> "...found or placed in good condition", and "...satisfactory in all respects for the service for which the ship is intended."

The following four-pronged approach to equipment maintenance would typically represent the implicit requirements of these societies.

* Condition Based Monitoring Systems
* Planned Maintenance Systems
* Continuous Survey Via a Certified Chief Engineer
* Society Visual Inspections

5.2 Current Society Assessments of Main Engine Failure Modes

Since vessel safety and reliability are two of the classification societys' primary roles, they have recently examined a large variety of main propulsion engine failure modes. To approve, or require, sophisticated surveillance schemes monitoring parameters which are unreliable indicators of a failure mode would, of course, be a misdirection of effort and finances, and may even provide deceptive security; and of course, to pursue the monitoring of failures that seldom occur would be imprudent.

Lloyd's and Det Norske Veritas have each analyzed reported casualties of slow speed and medium speed main propulsion systems over various time reported periods. Lloyd's has reviewed the ten year period from 1970 to 1980 and Det Norske Veritas has examined the two year period 1974 to 1975. The results of the Lloyd's survey, which provides a more extensive data base due to the longer time period analyzed, are detailed in Figure 5-1.

A description of each failure mode also appears below:

* Bearings.........excess wear, wiping, disintegration

FIGURE 5-1

OBSERVED MAIN ENGINE FAILURE MODES FOR SLOW AND MEDIUM SPEED MAIN PROPULSION DIESELS ON LLOYD'S REGISTER CLASSED VESSELS AS REPORTED TO LLOYD'S FOR THE PERIOD OF 1970 THROUGH 1980 (REFERENCE 15)

RANK	SLOW SPEED MAIN ENGINES			MEDIUM SPEED MAIN ENGINES		
	S/Speed 8000 SHP	S/Speed 8000-18000 SHP	S/Speed 18000 SHP	M/Speed 8000 SHP	M/Speed 8000-18000 SHP	M/Speed 18000 SHP
1	Crosshead Bearings (4.1)	Crosshead Bearings (5.3)	Crosshead Bearings (8.1)	Main Bearings (3.3	Main Bearings (6.7)	Main Bearings (18.4)
2	Cylinder Liners (2.8)	Cylinder Liners (4.6)	Turbo-Chargers (6.2)	Turbo-Chargers (3.3)	Pistons (6.4)	Crank Bearings (14.3)
3	Turbo-Chargers (2.8)	Turbo-Chargers (4.6)	Cylinder Liners (5.5)	Crank Bearings (2.9)	Turbo-Chargers (6.0)	Turbo-Chargers (13.9)
4	Pistons (2.7)	Pistons (3.9)	Pistons (5.4)	Valves & Vlv Gear (2.5)	Crank Bearings (5.4)	Pistons (13.2)
5	Crank Bearings (2.4)	Crank Bearings (2.4)	Cylinder Covers (4.2)	Cylinder Liners (2.4)	Valves & Vlv Gear (4.4)	Valves & Vlv Gear (7.6)
6	Others (1.9)	Cylinder Covers (2.0)	Crank Bearings (3.2)	Pistons (2.2)	Bedplate (3.5)	Internal Gears (5.9)
7	Main Bearings (1.8)	Others (1.6)	Others (2.5)	Others (2.2)	Others (2.9)	Others (5.2)
8	Cylinder Covers (1.4)	Main Bearings (1.2)	Cylinder Jacket (1.5)	Bedplate (2.0)	Cylinder Liners (2.5)	Cylinder Covers (4.9)
9	Valves & Vlv Gear (1.3)	-----	Camshaft (1.5)	Cylinder Covers (1.6)	Cylinder Covers (1.9)	Cylinder Liners (3.8)
10	-----	-----	Main Bearings (1.2)	Camshaft (1.4)	Camshaft (1.8)	Bedplate (2.8)
11	-----	-----	Internal Gears (1.4)	Internal Gears (1.2)	Governors (1.4)	Seatings (2.1)
12	-----	-----	Cylinder Entablature(1.4)	-----	Seating (1.3)	Cylinder Entablature(1.4)
13	-----	-----	Seating (1.1)	-----	Cylinder Entablature (1.2)	Cylinder Jacket (1.0)
14	-----	-----	-----	-----	Fuel Pumps (1.0)	-----
15	-----	-----	-----	-----	Intl. Grs (1.0)	-----

* Cylinder Liners...cracking, overheating, excess wear
* Turbochargers.....bearing wear, fouling
* Pistons...........cracking, overheating, broken-jammed - worn rings
* Valves............seized/jammed, burnt, disintegrated
* Valve Gear........excess wear
* Cylinder Covers...cracking, overheating
* Camshafts.........fretting-flaking, scuffing, broken-sheared
* Fuel Pumps........seized-jammed

A casualty is defined as an incident in a given date in the machinery, and neither the severity nor the extent of the casualty is taken into account.

Slow speed engines are defined as having a speed less than 300 RPM with the medium speed engines 300 RPM to 800 RPM.

In order to normalize the occurence of casualties with the operating time, the incidence of casualties per 100 years of accumulated ship service is also given in parentheses. It should be noted that the casualty data given relates only to ships class with Lloyd's Register where the casualty was reported. It may well be that many casualties occur which are not reported, particularly when they are of a minor nature and accordingly, the figures stated will tend to be on the conservative side.

For medium speed diesel engines, the high incidence rate of bedplate defects noted for medium speed engines is influenced by one particular type of engine which has now been modified to correct the problem and accordingly, is not a true reflection of casualty incidences which would normally be expected.

The next illustration, Figure 5-2, indicates the probabilities of a casualty incident occurring on medium and slow speed engines as the service life of the installation increases. This information is derived from the same survey mentioned earlier. Generally, the probability of a casualty incident rises progressively as the service life increases. It can also be seen that the probability of a casualty incident occurring on a diesel engine increases as the power range of the engine increases.

The main point of these illustrations is to emphasize the fact that casualties can, do and will occur. Additionally, some of today's high horsepower, multi-cylinder diesels have over an 80% probability of operating with a casualty just after the first few years of service.

5.3 Future Society Requirements in Performance and Condition Monitoring

Today the technical and economic aspects of the shipping world are changing rapidly. Factors such as new Inter-Governmental

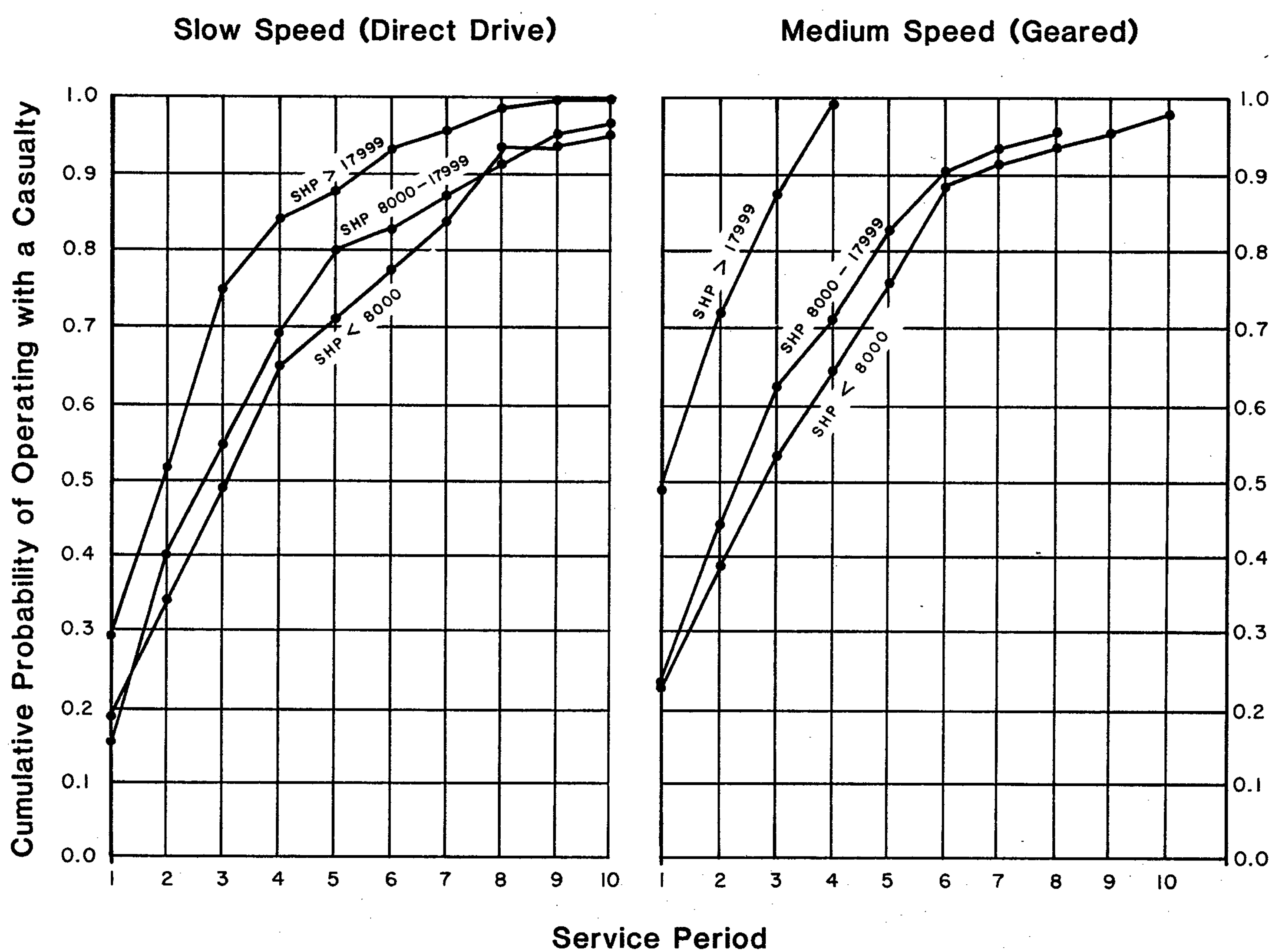


FIGURE 5-2

PROBABILITY OF OPERATING WITH A CASUALTY
VERSUS
PERIOD IN SERVICE
(REFERENCE 15)

Maritime Consultive Organization (IMCO) annual survey requirements, deteriorating fuel quality and vacillating economic climates contribute to this volatility. Many of these unquantifiable factors substantially affect the intelligent application and assessment of condition monitoring systems. Reduction in crew sizes, varying skill levels and steadily increasing diesel "normal" overhaul periods all play a role in the integration of performance monitoring and condition monitoring equipment into the transportation/classification society relationship.

Additionally, many classification societies differentiate between "performance" monitoring and "condition" monitoring. Although both are interrelated and in some cases even overlap. Most societies feel that their traditional mandate dictates that they concentrate on the "condition" and "safety" aspects of the vessel rather than on the economic ones.

Most of the societies interviewed felt that, in the future, condition monitoring will not substantially affect their traditional role in diesel plant inspection and classification. Normal component overhaul periods are significantly shorter then the required inspection intervals. The shipowner must usually open and disassemble the engine due to operational necessities prior to any scheduled survey requirements.

6.0 FOREIGN VESSEL OPERATOR/OWNER PRACTICES

6.0 FOREIGN VESSEL OPERATOR/OWNER PRACTICES

European and Japanese vessel operators have had substantially more experience with diesel plant maintenance and operational characteristics than their U. S. counterparts. This experience has also included considerably more exposure to specific diesel condition and performance monitoring systems. In order to take advantage of this wealth of information, detailed technical interviews were conducted with nine foreign vessel operators. The primary thrust of these interviews was aimed at identifying current operational practices and defining realistic operator expectations. Various operational advantages and disadvantages were also discussed and future performance and condition monitoring requirements were addressed.

The operators chosen for participation in this program are responsible for the maintenance of approximately 360 diesel powered vessels. Various levels of condition and performance monitoring techniques have been applied on 55 of these vessels. This sample represents a total of nearly 70 slow and medium speed main propulsion engines. Figure 6-1 provides a breakdown of these quantities.

FIGURE 6-1

LIST OF VESSEL OPERATORS
VERSUS
ENGINE TYPES FITTED WITH PERFORMANCE AND CONDITION MONITORING EQUIPMENT

ENGINE TYPE	VESSEL OPERATOR									TOTAL ENGINES BY TYPE
	A	B	C	D	E	F	G	H	I	
Slow Speed/Two Stroke with Exhaust Ports	1	8	3	-	14	-	2	1	-	29
Slow Speed/Two Stroke with Exhaust Valves	-	-	1	4	5	3	2	-	-	15
Medium Speed/Four Stroke	-	-	-	-	9	-	16	-	-	25
Total Engines by Operator	1	8	4	4	28	3	20	1	-	69

6.1 Operational Factors Influencing Performance and Condition Monitoring Choices

Many external factors affect the intelligent assessment of any vessel's performance and condition monitoring needs. Many of these items are completely beyond the control of the vessel operator, while others are more easily manipulated. The following is a compilation of various operational considerations that must be carefully examined by the vessel operator prior to the implementation of any condition or performance monitoring system.

These factors are arranged into two broad categories. The first set of items characteristically determines whether any major performance or condition monitoring programs should be utilized at all. For example - a vessel may trade on a short tramp type route constantly maneuvering in and out of port with no extended periods at relatively stable engine power levels. It would be next to useless to invest in a trend and diagnostic program when the propulsion plant is rarely run at a consistent power level long enough to be adequately monitored.

The considerations within this first group usually provide a "go - no go" type of decision for a proposed performance or condition monitoring program.

* Vessel Trade Route and Operating Characteristics
* Engine Normal Power Levels
* Crew Skill Levels and Expected Involvement
* Economic Marketplace Pressures, (operating cost versus capital costs)
* Expected Current and Future Fuel Availability

As identified during the vessel operator survey, the second set of factors identified below became increasingly important as the vessel's engineering staff actually attempted to formulate a coherent performance or condition monitoring system. The factors include:

* Engine Type and Failure History
* Retrofit/New Building Considerations
* Existing Performance and Component Maintenance Programs
* Shore Based Capability and Operating Philosophy
* Availability of Adequately Trained Technicians

* Union Considerations

* Flexibility of Insurance Premiums

6.2 Operator Experiences

The type of vessel operator interviewed ranged from the large fleet operator, (112 motor vessels), to the small independent tanker operator, (12 motor vessels).

Generally, it became apparent during the survey that the Scandanavians have approached the performance and condition monitoring field more aggresively than their European and Japanese counterparts. In the mid-seventies, many large, sophisticated, computer-based, diagnostic systems were developed by the northern European research organizations and implemented by their associated operators. Many of our discussions with these vessel owners centered around their assessment of the success of these systems.

The consensus was that, in many areas, too much data was disgorged from these systems, with no apparent consideration of the information's usefulness to the vessel operator. A number of new technological solutions were applied to interesting engineering problems, but the end result was that in a good number of cases, there was not sufficient reason to gather and process the esoteric data in the first place.

The standard advice from the vessel operators was to first define the problems at hand and then solve them, usually one at a time and not by installing a large, centralized computer. The difficulties must be resolved by breaking them down into their many facets - people, engines, vessel, logistics, money, time, technology, etc. In this instance it appears that the classification societies have also realized the usefulness of this multi-faceted, "systems" type approach.

However, it should also be noted that during the middle to late seventies when these systems were being evaluated, a good number of economic market pressures were shifting due to the steadily escalating oil prices. Capital resources were reallocated to support operating budgets and there simply was no money available to purchase prototype systems. The short-term, quick payback period had arrived.

In retrospect, the results from this period from both a technological and economic viewpoint were mixed. Many of the large computer-based systems have simply vanished. Sophisticated algorithms were developed for trend prediction but in practice they seldom replicated the actual thermodynamic and physical degradation processes of the equipment. This

resulted in inaccurate trend prediction under many circumstances and eventual loss of credibility.

From an economic standpoint the ground rules seemed to be constantly shifting. The expansive economic acquisition climate suddenly shifted to a "bare bones/pay our own way" type of environment. Needless to say, the effect of this climate on the fledgling performance and condition monitoring field was less than encouraging. Many equipment suppliers, engine builders and operators chose to back off and wait for a more favorable climate.

This short-sighted view is beginning to dissipate and many vessel operators are again looking toward long-term benefits. Many of these items are outlined in the following sections.

6.2.1 Tangible/Intangible Benefits Derived from Performance and Condition Monitoring as Actually Experienced By Operators

The following list of benefits, as described by vessel operators, is not in any order of rank or priorority and certainly does not represent a consensus. Some operators experienced significant savings with the systems, some felt that the equipment had yet to prove its worth. The potential benefits are as follows:

* Increased confidence level of the operating engineers in the diesel propulsion equipment with this factor becoming increasingly more important due to steadily deteriorating fuel quality.

* Enhancement of engine diagnostic troubleshooting.

* Ease of information acquisition versus use of indicator diagrams.

* Claimed fuel savings of three to four percent.

* Although these diagnostic systems do not enable the operator to reduce crewing per se, they do become a positive factor in making the operating burden more amiable to a crew that may have already been reduced due to other considerations.

* Equipment can be readily integrated into an overall condition maintenance program.

* Extension of piston overhaul periods versus calendar periods.

6.2.2 Performance and Condition Monitoring Difficulties as Voiced by Vessel Operators

The following list identifies the major difficulties with these systems as experienced by the surveyed operators.

* Cost - Initially the cost of a large system approached the cost of an extra cylinder. Obviously if this money was spent on a higher horsepower engine running at a lower service margin, a substantial amount of performance and conditioning monitoring "insurance" would result.

* Inadequate and incomplete commissioning and start-up of the entire system including sensors, cabling and on engine equipment.

* Large centralized computer systems are much less desirable than decentralized, distributed units. The crew must also be able to deal with this flow of information. Some systems require too much time and dispense too much information. When the magnitude of data becomes too great, the operating engineer often ignores it all and reverts back to previous operating routines.

* The engine builder must be continuously involved. If not, there is a certain amount of reluctance to share engine data. Interface between the electronic vendor and the engine builder must also be maintained. The difficulty arises in normalizing and correlating the physical and thermodynamic engine characteristics to the appropriate electronic acquisition and evaluation routines.

* Trend analysis and prediction have proven to be costly and impractical.

* Although crew training normally consists of no more than in-service operation with a few days familiarization, the operating manuals must contain explicit, concise, and easily understandable information. This has typically not been the case.

* For much of this equipment to be useful there must be sustained periods at stable engine power levels. High utilization, fast turnaround, high maneuvering, short trade route type vessels may make this impractical.

* The sensors, cabling and system reliabilities must be improved and sufficient technicians must be available to service the equipment.

* And lastly, econimic payback. Return-on-investment and economic payback are very difficult to quantify. The cost of "not breaking down" is hard to prove. More tangible savings such as fuel are also subject to interpretation. More than one operator mentioned that fuel savings of less than three percent are extremely difficult to measure accurately.

6.2.3 Recommended Modifications to Current Systems on the Market

The following list summarizes the vessel operators recommendations, based on their experience, relative to the approach which should be taken by the diagnostic systems' manufacturers with respect to their systems' configurations, services, and areas of technical development.

* Decentralize and use the approach of modularized, dedicated equipment.
* Delete trend analysis and prediction features until more reliable (if ever)!
* Ensure adequate system check-out and commission.
* Delete hard copy diagrams.
* Improve sensor and installation reliability.
* Develop more reliable prediction of exhaust valve failures.

6.3 Vessel Operator Recommended Practices

The following performance and condition monitoring recommended practices are based on the operators' views, encompassing all types and sizes of systems.

Their recommendations depend heavily on their own particular economic and technical circumstances. Many operators were greatly enfluenced by prior experiences with specific engines and systems. Each situation becomes unique due to the impact of the various factors previously outlined in Section 6.1, but generally their recommendations were aligned along the lines of basic engine types. The following details synthesize the current vessel operator recommended practices for each engine type. The recommended subsystems under each engine type are arranged in order of desirability.

6.3.1 Slow Speed/Two Stroke Engines with Scavenging Exhaust Ports

* The most common application of condition monitoring

to these engines is the inclusion of piston ring condition and wear surveillance. One engine builder markets their own design and the operators are comfortable with its use.

* Next in desirability is the installation of liner temperature monitoring for blow-by and scuffing. Past experience with these designs, in the longer skirt modes, proved the worth of these diagnostic systems.

* The desire for combustion monitoring for this engine had less to do with the manufacturer's needs than with the operator's desire to have more information about this process during these times of uncertain fuel quality.

* Lastly, there was the general agreement in noting the desirability of adequate gas and air path monitoring. Although opinion was divided as to the means of acquisition and data display all felt that more reliable information is necessary in this area.

6.3.2 Slow Speed/Two Stroke Engines with Exhaust Valves

* The simplicity of this manufacturer's scuffing detection system made this the first choice among vessel operators. This fact, coupled with the potential for saving lube oil, provided a positive atmosphere for this system to be easily accepted.

* Due to this engine design, the vessel operators paid significantly more attention to the exhaust gas path. They all felt that this engine would benefit considerably from closer scrutiny of this parameter and the following two functions.

* Combustion pressure sensing has always traditionally been utilized in monitoring this engine type. The operators felt that the increased accuracy and repeatability from new pressure sensing technologies would provide a higher level of confidence to the engineers regarding the propulsion machinery.

* Fuel injection pressure was hesitantly mentioned as the final recommended diagnostic tool for this engine type. Basically, since the liners, air/gas path, and the combustion processes have been recommended to be monitored, most felt that this one extra step would easily complete this performance and condition monitoring package.

6.3.3 Medium Speed/Four Stroke Engines

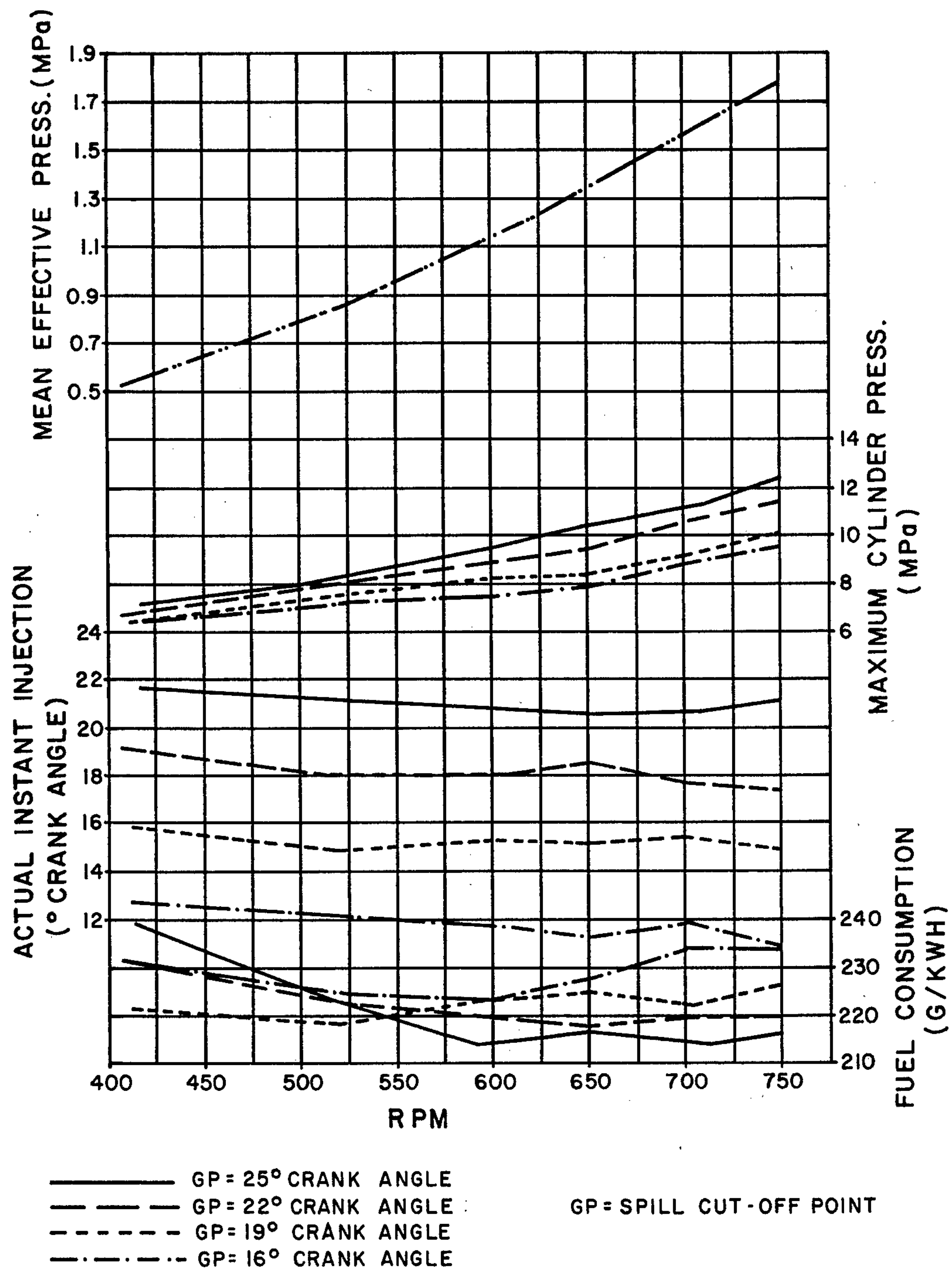
* Number one and number two on every operator's list was main and crankpin bearing temperature monitoring. Sections 2.5, 3.2.6, and 4.5 all address these areas in detail. As previously mentioned, there is no unaminity in this area as to the preferred temperature monitoring technique, but it seems as though metal shell RTD's for the main bearings and non-contact/wireless thermistors for the crankpin bearings are reasonable, adequate solutions utilizing today's technology.

* It was previously pointed out in Sections 3.0 and 4.0 that these medium speed, multi-cylinder engines may have the potential for effective utilization of various performance monitoring techniques. This was primarily due to the large number of cylinders and the likelihood that there would be incorrect fuel/combustion adjustments on a number of these cylinders. Figure 6-2 depicts the effects of injection settings versus fuel consumption and other parameters on a 750 RPM, 1320 KW medium speed diesel propulsion engine. About half the vessel operators felt that combustion pressure monitoring would be beneficial in these areas.

* Since high thermal loading and large air throughputs are characteristic qualities of these engines, all of the vessel operators felt that increased surveillance of the air/gas path was extremely cost effective.

FIGURE 6-2

MEDIUM SPEED DIESEL INJECTION SETTINGS
VERSUS FUEL CONSUMPTION
(REFERENCE 16)



7.0 APPLICATION GUIDELINES AND RECOMMENDED STANDARDS FOR U. S. DIESEL PROPELLED VESSELS

7.0 APPLICATION GUIDELINES AND RECOMMENDED STANDARDS FOR U. S. DIESEL PROPELLED VESSELS

The installation of the vast majority of diesel performance and condition monitoring equipment is considered optional. Neither the classification societies nor the regulatory bodies currently require these systems. This decision rests solely with the vessel operator. In considering these systems, the following questions should be addressed.

* What should the objectives of the vessel operator be?

* Can the ship owner's current operations support a performance and condition monitoring system effectively?

* How can the vessel owner effectively attain his identified objectives?

The answers to these questions are primarily found by assessing the numerous technical concerns, operational factors and economic realities of each individual vessel within each specific fleet.

The following recommendations provide the ship owner with appropriate technical and operational guidelines to enable him to answer these questions and to make an intelligent decision regarding the acquisition and installation of these systems.

The proposed standards also present the rationale behind the selection of each recommendation and lay the groundwork for the presentation of a summary matrix encompassing both medium speed and slow speed diesel propulsion plants. As to the basis of these recommendations, the following approach was taken:

If an individual practice was technically sound, and it was clearly suggested by all surveyed, it was then included as a recommended standard. To this extent, these guidelines represent a synthesis of all the recommended practices and operator experiences detailed in earlier sections.

Due to the wide range of opinions, unanimity was rarely the case. In many instances, there were major disagreements regarding the selection and application of these systems. Simply reporting a consensus was seldom possible. In these areas, each recommended standard was largely based on its potential operating benefit, its operator acceptance, and its technical credibility.

These guidelines and recommendations are designed to provide a certain amount of latitude in the utilization of new

monitoring techniques, the methods of achieving functional requirements, and the choice of different types of performance and conditioning monitoring (PM/CM) equipment. These recommendations should be considered flexible. If alternate methods evolve from advancements in technology which provide the same monitoring or end results then these methods should be evaluated on their own merit.

7.1 Scope

The following sections present the application guidelines and the recommended standards for the acquisition, installation and operation of performance and condition monitoring systems on a typical medium speed or slow speed diesel propulsion plant in excess of 3,000 HP. The vessel would normally be operated with a minimum watch or unattended engine room with an operating profile which includes steady steaming and maneuvering modes.

Although the application guidelines will address various operating situations, the recommended standards are based on the foregoing vessel operating on a reasonably fixed trade route, with a minimum sea passage of approximately 36 to 48 hours at a relatively constant power level. These requirements address bulk cargo, dry cargo and container vessels which are propelled by liquid fueled diesel engines. These recommendations only address the machinery and systems associated with the diesel prime mover. Equipment involving the secondary auxiliary systems or cargo handling systems are not addressed within the scope of these recommendations.

The individual diesel subsystems addressed are outlined below.

* Cylinder Combustion Processes
    * Pressures
    * Angles
    * Outputs
* Fuel Injection Processes
    * Pressures
    * Angles
    * Temperatures
* Air/Gas Path Processes
    * Ambients
    * Abs. and Δ Pressures
    * Abs. and Δ Temperatures

* Cylinder Components
  * Rings
  * Pistons
  * Liners
* Air/Gas Path Components
  * Filters
  * Coolers
  * Turbochargers
  * Exhaust Valves/Scavenging Ports
* Drive Train Bearing Components
  * Main Bearings
  * Crank Pin Bearings
  * Crosshead Bearings
  * Thrust Bearings
  * Camshaft Bearings
* Heat Exchanger Components
  * Main Coolers
  * Auxiliary Coolers
* Fuel Oil Delivery Components
  * Preheaters
  * Filters
  * Separators
  * Quality

7.2 Preliminary Guidelines and Principles

As noted previously there are numerous operational and design factors which influence the choice of performance and monitoring equipment. Before analyzing the merits of each individual technical item, the ship owner must first ask the following questions:

7.2.1 What Should the Objectives of the Vessel Operator Be?

The answer to this, of course, depends on many variables: Is this a retrofit or a new building? Is there a continual history of engine failures? Are excessive fuel costs versus versus maintenance costs driving the operation of the vessel? Are there shore-based personnel available to support the system? Can the appropriate level of training be provided which is consistent with crew proficiency, etc?

The majority of participants in the survey indicated that the first item of priority should be component condition monitoring. Vessel reliability is not a luxury. Before any operator can begin to optimize his performance, the schedules must be met and unanticipated downtime must be avoided. If the vessel is continuously being detained, for example by wiped bearings, then that particular problem should be addressed immediately. It may be a matter of lube oil contamination or crankshaft misalignment. But it may also be due to wear that could be predicted by more sophisticated monitoring techniques.

The point of the matter is that the operator must look at the particular vessel in question and analyze its operating history. It does no good if you supply an elaborate solution to a non-existent problem.

If the vessel is a newbuilding project, the engine builder should supply a casualty history of that particular engine type. A survey of the spare parts actually consumed in service for that particular engine type should suffice in pointing out the major problem areas.

Although the following point has been repeatedly mentioned throughout this report, it needs to be re-emphasized:

* Insure that the engine builder is involved at every stage. Although he may not agree with all the decisions of the vessel operator, his input is vital to the success of any performance and condition monitoring system.

It appears that the most successful applications of condition monitoring are where operators tailor their installations to individual propulsion plants and operating philosophies. A generalized or "shotgun" approach in this area seems to be costly and ineffective. Additionally, not withstanding individual difficulties, the slow speed/two stroke propulsion plant appears to benefit most from the implementation of component condition monitoring equipment. This is primarily due to the capital intensive characteristics of their replacement spare parts. Additionally many of the component condition monitoring systems were specifically designed for these slow speed, two stroke units.

As to any additional monitoring, once the reliability of the vessel has been addressed, the performance factors can then be evaluated.

When assessing performance monitoring a good deal depends on the existing operational characteristics of the vessel. If the crew is using conventional instrumentation and maintaining optimum fuel rates, then much of the performance monitoring equipment may be superfluous. If in fact there

is a potential for improvement, then serious consideration of additional equipment is in order. One must always remember that small improvements in propulsion plant efficiency provide large economic returns. The electronic manufacturers claim that the typical potential fuel savings are in the 2-4% range for the slow speed diesel and 6-8% for the medium speed, four stroke unit.

Most European and Japanese vessel operators believe that their crews are running their slow speed engines at or near their optimal values with conventional instrumentation. Conventional performance monitoring of these diesels is basically a mature, if not optimum, technology. Many system deviations are detectable even with the traditional methods. For example, as pointed out in Section 3.1.1, a deviation of only one degree in injection timing may cause a 5% penalty in fuel economy. This significant discrepancy alerts the engineer to probable performance difficulties.

There seems to be more of a potential benefit in the application of performance monitoring equipment to the medium speed, four stroke units. While individual thermodynamic deviations produce less of a fuel penalty than on their slow speed counterparts, the overall effect of multiple cylinders and multiple engines compound the effect of these deviations. Further, medium speed engines are more likely to be running at less than optimum performance levels due to the lack of adequate conventional instrumentation.

In summary, it appears that if the crew is attentive to the slow speed diesel operation the primary value of the performance monitoring equipment is in its utilization as a diagnostic tool and not as a "fuel saver." On the other hand, the medium speed engines may benefit considerably in the performance area from the application of "selected" performance monitoring equipment.

7.2.2 Can the Operator Effectively Utilize a Performance or Condition Monitoring System?

The following five areas must be adequately addressed in order to determine the potential effectiveness of any performance or condition monitoring plan.

* Trade Route: The vessel's trade route must contain a reasonable time period for the crew to perform adequate condition and performance monitoring work on the engine. If the crew's time is continually consumed by ship's evolutions (maneuvering, ballasting, fueling, loading, discharging, etc.), then it is usually unwise to add another routine to their schedule. It may be more beneficial to utilize a shore-based "flying squad" maintenance concept in these areas.

* Engine Power Levels: Basically, steady state power levels are necessary for realistic condition and performance monitoring. Data skewed far down on the performance curves are not necessarily reliable. If a ship is continually "slow steaming," serious inaccuracies can occur in attempting to extrapolate this data to the upper power levels.

* Crew Skill Levels and Expected Involvement: One of the key factors in the majority of the successful performance and condition monitoring installations is the owner's insistence that the operating engineer "remain in the loop." As soon as the monitoring equipment was looked upon as a cure-all, or a piece of electronics to be used by others, the program failed. The engineer must stay involved and use the equipment as a tool. This is certainly how it has been the most effective in the past.

* Economic Marketplace Pressures: It is obvious that if new capital funds are unavailable or if the operating costs reduce the vessel's margin to a negative value, any investment in equipment necessitates major financial decisions. Additionally, each operator must determine the potential cost of lost time and lost cargo. One can only say that these factors must not be ignored in the overall technical evaluation.

The previous four factors are basically prerequisites for the successful implementation of any performance and condition monitoring system. These factors must all be satisfied if the contemplated performance and condition monitoring system is to have any degree of success.

The following final item is different in one respect from the previous factors. That is, if it is presently a major concern in vessel operations, then this by itself, may necessitate the installation of a higher level of performance and condition monitoring. The item in question is, of course, fuel oil quality and condition.

* It must be noted at the outset, that today there are many techniques to prevent fuel quality induced damages. Filters, purifier-clarifiers, homogenizers, etc. are all available. However, there are no reliable, universally successful means of predicting fuel precipitated difficulties.

  Although no positive relationship between poor fuel quality and its combustion characteristics has been proven, the effects of poor fuel condition

on specific components are unarguably evident. The current condition and performance monitoring equipment may not predict failures due to poor fuel but it certainly will inform the operator of a deteriorated condition sooner than conventional instrumentation.

7.2.3 How Can the Vessel Operator Attain the Foregoing Objectives?

The ship owner can best ensure the success in applying diagnostics to diesel engines or any piece of machinery by staying actively involved in the acquisition and installation of the proposed performance or condition monitoring system. The operator should review and analyze the following guidelines detailed in Section 7.3 and adopt the recommended standards outlined in Sections 7.4 and 7.5 to his particular needs.

7.3 Design and Operational Guidelines

As described above, the following specific guidelines and recommended standards should be evaluated and customized to meet the needs of each individual operator.

7.3.1 System Architecture

A large, centralized computer system has proven to be an uneconomical and unwieldy solution to the diesel performance and condition monitoring problem. Centralized processors with core, disc, cassette or paper tape memories have been difficult to effectively program and maintain.

Most European and Japanese ship owners professed an overwhelming preference for stand-alone, modular, microprocessor type units. These dedicated subsystems appear to be more acceptable to the crew and are psychologically more manageable. Additionally, an isolated failure does not cause an entire monitoring system to be disrupted and when the individual subsystem can be repaired relatively quickly, an acceptable level of credibility is maintained.

Battery back-up power should usually be provided if there is any danger of memory volatility.

The technical expertise of the crew and the service personnel in these areas must also be addressed. Experience seems to indicate that individual modular units such as those described above are more amenable to third party service and maintenance.

7.3.2 System Hardware and Installation Practices

Many of the performance and condition monitoring sensors represent the leading edge of today's technology. Due to this, they lack the years of field experience needed in order to refine their physical and electrical characteristics. Sufficient durability and questions of longevity usually dominated the survey discussions.

When choosing sensors and their locations use a conservative approach. Specify the best environmental and electrical characteristics that your budget will allow. Specify duplicate sensors in inaccessible locations such as cylinder liners. Benefits in these areas due to reduced expenditures are sometimes imaginary.

Data transmission by analog, digital and multiplex means have all been employed successfully. The transmission of conventional pressure and temperature information is least susceptible utilizing a 4-20 ma dc current mode. This type of system usually requires no external shielding and is relatively impervious to electrical and magnetic disturbances.

Cathode ray tubes (CRT's), have suffered from environmental failures in the past. The primary culprit is vibration. If a sophisticated graphic display is utilized, ensure that it meets stringent maritime specifications. It may even be desirable to require military specifications and performance.

Regarding installation practices, if one realizes that the installation of this equipment may cost three times its acquisition cost the importance of controlling the quality of the installation is portrayed in a clearer perspective. Certain operators have experienced delays as long as one and one-half years before their systems wre fully commissioned and operable. Of course, not all of these delays were due to installation problems, but a good deal of them were. A high quality installation and the correct commissioning of all sensors, cables and components are mandatory requirements necessary for system success.

7.3.3 Integration of Performance and Condition Monitoring Equipment With the Engine Room Unattended Automation Systems

The ship owner may have the opportunity of choosing between integrating the performance and condition monitoring equipment into the unattended automation system or leaving it as a stand-alone type of system.

The classification societies have not firmly decided one way or the other in this matter. The electronics systems manufacturers prefer that this equipment be integrated due to their belief that the system will then receive better attention and maintenance.

Not withstanding the above, it appears that the overriding concern of the vessel operator must be reliability. If there is any possibility that the performance and condition monitoring equipment will degrade the normal operation of the automation system via internal or external faults, then complete equipment segregation is necessary rather than any attempt at system integration.

7.3.4 Man/Machine Interfaces and Data Utilization

The operator must choose the basic display format and operating mode for each subsystem. Many questions must be answered. Are central displays preferable to modular units? Should the subsystems utilize display features only, with no hard copy or plots? Do performance deviation calculations provide meaningful data? Are maintenance predictions and automatic trend line analyses desirable?

Firstly, the presentation of information should be concise, understandable, and above all, be kept to an absolute minimum. In the past, the reams of information produced by data logger based systems have typically gathered dust in some remote corner of the home office.

As to display format, individual digital or analog displays are preferable to the centralized CRT type systems. Although the new CRT/video display techniques may be convenient and attractive from a "systems" standpoint, they suffer from many of the inherent disadvantages of large, centralized, processing systems.

Hard copy, or data print-outs, are only recommended for the combustion processes and the piston ring subsystems. No plotter capabilities for pressure/time or pressure/volume diagrams are suggested. Most of the operating engineers today only utilize the absolute data and seldom review the pressure wave forms.

Performance and condition deviation data appear to be meaningful only within the 20 to 100 percent (MCR) range of the propulsion engine. Although limited to this band, this information can be useful in defining a baseline for engine performance and condition monitoring and is therefore recommended.

The viability of automatic maintenance prediction and trend line analyses is another matter. These systems

have been unsuccessful in the past and are not suggested. The predictive algorithms have proven troublesome and ineffective. Their basic difficulty seems to be that the mathematical models fail to replicate the actual physical and thermodynamic degradation processes of the engine. Additionally, in automatic prediction calculations, no engineer is in the evaluation loop. The operating or shoreside engineer normally serves to segregate faulty or erroneous data from this evaluation process. This valuable "buffer" is missing in most automatic analysis and predictive maintenance systems.

Even though automatic maintenance prediction appears to be currently unrealistic, the operator must still evaluate and act on the collected performance and condition data. Basically, there seem to be three general paths that the ship owner can follow.

* Rely on the performance deviation data from the onboard systems and manually plot the trend data after correcting and normalizing it on the vessel. Trend predictions can then be forecast from this information. See Figures 2-2 through 2-4 for examples.

* Gather the performance and condition monitoring data onboard the vessel on a regular basis. Enter the information on systematic data forms and send it to a shoreside marine staff or the engine builder for normalization, analysis and maintenance scheduling.

* Arrange for a "flying squad" type of approach to performance and condition monitoring. That is to say conduct periodic shipboard audits of the fleet using company office based specialists. Supplement the basic onboard diagnostic equipment with more sophisticated, portable analyzers. This approach will provide a "snapshot" type of view of the engine condition rather than the longer term, more detailed trend analysis approach.

In the final analysis the vessel operator must choose the maintenance procedure that best suits his resources and abilities.

7.3.5 Performance, Design and Environmental Criteria

* Accuracy and Repeatability

  The combustion process monitoring accuracy should generally be at least $\pm$ 3 percent of the measured value for meters and digital displays, or the scale division, whichever is smaller,

at the rated normal operating condition. The air/gas path monitoring accuracy should be $\pm$ 1 percent of full scale span for meters and displays with long-term stability and low drift characteristics. The repeatibility for both should be at least $\pm$ 0.3 percent.

All other display accuracies should generally be $\pm$ 2 percent of full scale span.

The above requirements should be met for the end product (i.e., the displayed or monitored variable) and should include all the individual errors in sensing and signal transmission.

* Reliability

The diagnostic system characteristics should not be constrained by excessively short component lifetimes. Since the dynamic pressure sensors appear to be the limiting factor in this instance, they should be specified with a life expectancy in excess of 6000 hours to ensure system availability.

* Location of Equipment

The data acquisition and preprocessing devices should normally be located in the engine room near the diesel propulsion unit. The processing, recording and display equipment should be located in an environmentally conditioned control room.

* Interference

Conducted interference, including power frequency harmonics, spikes and surges, plus radio frequency energy should be excluded by means of isolation and filtering networks. Cable insulation degradation down to 200 KΩ should not affect system operation.

* Component Requirements

All integrated circuits should be of the hermetically sealed type. No plastic "IC's" should be used.

All circuit boards should be epoxy coated with hermetically sealed active components.

Circuit boards should undergo a complete functional test, then a full 48 hour burn-in at 60°C with full power, temperature, and humidity cycling

and then a repeat functional test.

All "assembled systems" should also undergo a full functional test, then a full 48 hour burn-in at 60°C with full power, temperature, and humidity cycling and then a final functional test.

All electrical connections should be made at terminal blocks in the consoles. Each wire should be clearly marked with circuit and terminal number. Internal wiring from the terminal boards should be arranged in convenient groups with neatly arranged securing lacing. Low level signal wiring should be shielded and conductor harness assignments should be carefully segregated to eliminate interference from high level signals and preclude damage to vital circuits by a fault in any other conductor.

All wiring should be adequately protected from abrasion at all metal contact points.

To the maximum extent practicable, bolt-in modules with plug-in ribbon cable connections should be used in the construction on consoles and except for external wiring to consoles, all other connections should be through the use of plug-in devices to reduce field wiring.

Stress levels applied to each component should not exceed 50% of each component's rating.

* Power Supply Considerations

The following electrical operating conditions should not affect the operation of the diagnostic system.

Successive power breaks with full power between breaks.

Nominal voltage (+) 10% (-) 15% (stationary). Voltage transients (up to 2 sec. duration)(+) 20% of nominal.

For battery power sources: Nominal voltage (+) 17% (stationary). Voltage transients (up to 2 sec. duration)(+) 20% of nominal.

For AC systems: Nominal frequency (+) 5% (stationary). Frequency transients (up to 2 sec. duration) (+) 15% of nominal.

Where closer tolerances on voltage and frequency are required, special regulated power supplies should be provided. Voltage transients should not cause any dangerous malfunctioning or damage to the control and monitoring devices and the control equipment should be fitted with transient voltage suppressors.

The equipment should have impulse voltage transient protection from pulse transients with amplitudes of $\pm$ 1200 peak volts, rise times of 2 microsec. to 10 microsec., and durations of up to 20 microsecs.

* Temperature

All electrical devices are to be suitable for the applicable marine atmosphere. They are to be capable of performing their intended function in an ambient temperature ranging from $0^{\circ}C$ to $50^{\circ}C$.

All semi-conductor and other electronic devices are to be selected on the basis of an expected shipboard ambient air temperature range of $0^{\circ}C$ and $60^{\circ}C$ inside of consoles. Silicon and selenium semi-conductor devices are to be used in preference to germanium.

* Humidity

All equipment should operate satisfactorily with a relative humidity of up to 100% with condensation and temperature and humidity cycling.

* Corrosion

Enclosures, working and other parts of electrical equipment which would be damaged or rendered ineffective by corrosion should be made of corrosion-resistant materials or of material rendered adequately corrosion resistant.

Materials with a high resistance to corrosion and aging should be used. Metallic contact between different materials should not cause electrolytic corrosion in a marine atmosphere.

As a base material for printed circuit cards, glass-reinforced epoxy resin or equivalent should be used. Printed circuit cards should be preserved by a moisture protecting coating.

* Vibration and Ship's Motion

All control, actuating, monitoring and alarm devices are to be able to operate successfully when subjected to vibratory frequencies of 2 to 80 Hz in conjunction with peak to peak amplitudes of 2 mm (0.08 in.) for frequencies 2 to 13.2 Hz and an acceleration of 0.7 g for frequencies of 13.2 to 80 Hz. Care is to be taken to insure that mounting arrangements for the components will not amplify shipboard vibrations.

The control equipment should be designed to operate satisfactorily under the following conditions:

Transient	Permanent	Natural Period (Seconds)
$+30^{\circ}$ roll	$+15^{\circ}$ list	Roll: 8 min., 30 max.
$+10^{\circ}$ pitch	$+5^{\circ}$ trim	Pitch: 6 min., 25 max.

* Acceleration Forces

+1.0 g in the transverse direction
+0.5 g in the longitudinal direction
+1.5 g (plus deadweight) in the vertical direction

* Contamination

Salt-contaminated atmosphere up to 1 mg salt per m^3 of air, at all relevant temperature and humidity conditions. Oil mist and dust shall not affect the equipment operation.

7.4 Recommended Standards for Engine Diagnostic Systems on U. S. Slow Speed Diesel Propelled Vessels

Recommended standards for performance and condition monitoring systems on slow speed diesel propulsion plant systems are presented in the following sections. The rationale for each recommendation is also addressed.

A summary matrix of these recommendations appears in Table 7-1, Slow Speed Diesel Recommended Practices, pages 7- 25 through 7- 41.

7.4.1 Cylinder Combustion Processes - Slow Speed Diesel

The major benefit to combustion monitoring on slow speed engines seems to lie in its value as a troubleshooting and diagnostic aid rather than in its role as a performance

monitoring device. Improved measurement accuracies and repeatabilities coupled with ease of measurement and convenient displays make these instruments worthwhile. This new technology usually provides measurements with accuracies ranging from (+) 1% to (+) 3% and reproducibilities of (+) 0.3%. The accuracies of the earlier manual methods were approximately (+) 8% including unknown repeatabilities. Although these accuracies are superior to the manual systems, the important improvement is in the repeatability. The absolute data may not be exactly correct but the information provided by the relative values and their progression in a time basis is extremely useful. Therefore, combustion pressure monitoring is recommended for these slow speed diesel propulsion plants.

Single, air cooled or uncooled, pressure sensors are recommended for both a technical and economic standpoint. Multiple, permanently installed transducers are costly and seem to suffer from thermal and environmental effects. Some of the original transducers required air or water cooling, but recent designs can withstand temperatures up to 350°C for reasonable lengths of time.

It appears that piston position can be accurately determined without resorting to sophisticated individual cylinder probes. Rotary encoders or proximity pick-ups with ferrous pins and one TDC mark seem to be sufficient, although accurate installation and careful calibration is mandatory.

The specific measured parameters that are recommended are shown in Table 7-1, Cylinder Combustion Process, Slow Speed Diesel, page 7-25.

7.4.2 Fuel Injection Processes - Slow Speed Diesel

Although injection pressure monitoring is beneficial, most of the basic information necessary to diagnose component difficulties is available within the previously mentioned combustion data. Additionally, the injection pressure wave forms and their irregularities are difficult to adequately interpret without detailed analysis. While one may not be able to pinpoint specific deteriorated component as quickly without this feature, this seems to be acceptable to the experienced operating engineer.

Cylinder top cover temperature monitoring appears to be too difficult to normalize to any consistent baseline. Practically speaking, it seems as though this feature should be left to the test bed.

The individual parameters within this section are listed in Table 7-1, Fuel Injection Processes, Slow Speed Diesel, page 7-26.

7.4.3 Air/Gas Path Processes - Slow Speed Diesel

The most important aspect of monitoring this process is the utilization of accurate and stable instrumentation. High accuracy (± 1% or better), low drift transmitters or local instruments should be used.

The air side of the process does not require any elaborate trend analyses or exhaustive performance calculations. Cleaning the charge air coolers and inlet filters on a regular calendar basis yields significant results.

As to the exhaust side, no successful, accurate, and reliable method has been yet developed to adequately monitor thermal load and exhaust conditions. Because of this, good quality thermocouples and accurate exhaust gas monitoring equipment is a must. Standard pyrometer type systems are inadequate. Combustion monitoring data can supplement the exhaust temperature information to predict abnormal deviations.

Careful monitoring of this data is much more critical in certain slow speed engine designs with uniflow scavenged, valved, combustion chambers.

Recommended monitoring standards for these items are contained in Table 7-1, Air Gas Processes, Slow Speed Diesel, pages 7-27 and 7-30.

7.4.4 Cylinder Components (Rings, Grooves and Liners) Slow Speed Diesel

The recommended standards for cylinder component monitoring are highly dependent on the engine type. One major manufacturer of loop scavenged, slow speed engines offers its own piston ring monitoring system. This engine appears to benefit from this type of monitoring. Past service history on this engine type indicated that there was a potential need for monitoring in these areas. Additionally, visual inspection of cylinder components must be accomplished through the exhaust receiver rather than via inspection ports.

The other engine builder (who manufactures uniflow scavenged, valved, slow speed diesels) feels that frequent visual inspection of the rings, grooves, and liners is sufficient. This is easily accomplished via inspection and access covers specifically provided for this purpose.

Temperature monitoring of the liners to detect thermal loading anomolies is felt to be unnecessary. Prior thermal excursion difficulties have been resolved by each manufacturer with redesigned liner geometry.

Liner scuffing is another matter. One manufacturer provides their own scuffing detection system. This seems to be an ideal monitoring and protection system. It warns the operator of an immediate problem and enables him to do something about it (increase lube oil flow to the affected cylinder). During normal periods, it conserves cylinder oil. This system is recommended when that particular type of engine is installed.

Cylinder liner wear technology has not yet reached a sufficient level of maturity to provide adequate reliability and cost-effectiveness. Visual inspection and measurement during engine disassembly is still required.

Details of these recommendations are contained in Table 7-1, Cylinder Components, Slow Speed Diesel, pages 7-31, and 7-32.

7.4.5 Air Gas Path Components - Slow Speed Diesel

As mentioned in Section 7.4.3, various air side items such as coolers and filters are easily monitored by high accuracy, low drift, pressure and temperature transmitters or local instrumentation.

The evaluation of turbocharger compressors and turbines is more complex. Many variables interact and affect interrelated parameters. In order to effectively monitor these components, continuous trend plots must be maintained. Complex quantities such as turbine and compressor efficiencies should be calculated and plotted.

The basic choice in this matter is to either keep a close watch on the detailed data and trend indicators or ignore all but the basic information and concentrate on cleaning the air and gas path components via a regularly scheduled maintenance program. The choice depends on the vessel operator's resources and the skill of the crew.

Turbocharger bearing problems on slow speed engines have proven to be minimal. Therefore, no sophisticated vibration monitoring equipment is suggested.

Effective monitoring of exhaust valves, as previously mentioned, has proven difficult in the past. The most reasonable approach seems to be a combination of more intensive air/gas path monitoring as described above with increased integration of the newly developed combustion monitoring techniques into the overall maintenance scheme, and frequent visual inspection of the valves and valve gear.

Recommendations relative to these measurement parameters

are noted in Table 7-1, Air and Gas Processes and Components, Slow Speed Diesel, pages 7-33 through 7-34.

7.4.6 Drive Train Bearing Components - Slow Speed Diesel

The large capital investment in these engines and their casualty histories dictate that a more effective bearing monitoring system supplement the standard oil mist detectors. Return oil flow temperature RTD systems are usually offered as an option on most engines.

The recommendations focus on the utilization of multiple monitoring methods. RTD oil return flow systems plus crankcase vapor monitoring plus regular crankweb deflection readings are all suggested.

Details of these items are contained in Table 7-1, Drive Train Bearing Components, Slow Speed Diesel, pages 7-35 and 7-36.

7.4.7 Heat Exchanger Components - Slow Speed Diesel

Conventional differential temperature monitoring methods with local gauges or RTD's and transmitters are sufficient for these processes. Normally there is no sudden component failure and the performance loss is gradual.

The pH values and the chloride content of the fresh water system should be checked monthly with test solutions. A water sample should be analyzed ashore for additive and salinity control every two or three months.

Refer to Table 7-1, Heat Exchanger Components, Slow Speed Diesel, pages 7-37 and 7-38 for individual functions.

7.4.8 Fuel Oil Delivery Components - Slow Speed Diesel

Although most of the standard pressure and temperature instrumentation for this system is adequate for normal operation there is much to be desired in the fuel oil quality and condition monitoring area. Presently there seems to be no available, on-line, monitoring equipment that will warn the operator, even after the fact, that there is a fuel quality or condition problem.

One diesel manufacturer stated that 70% of their service calls were due to fuel condition related difficulties. One research organization conducting tests with condition monitoring equipment found that 20% of the bunkered fuel did not agree with the specification sheets.

Although the fuel oil delivery system is not specifically a part of diesel engine diagnostics, the following comments are offered.

Since there appears to be no easy way to avoid potentially bad fuel, the operator must ultimately be prepared to deal with this problem. Specific subsystems such as high quality filters, purifier-clarifiers, and homogenizers should all be investigated to lessen the potential penalties of poor fuel condition.

Table 7-1, Fuel Oil Delivery Components, Slow Speed Diesel, pages 7-39 and 7-40 represent the recommendations regarding standard instrumentation in this area.

7.5 Recommended Standards for Engine Diagnostic Systems on U. S. Medium Speed Diesel Propelled Vessels

Recommended standards for performance and condition monitoring syhstems on medium speed diesel propulsion plant systems are presented in the following sections. The rationale for each recommendation is also addressed.

A summary matrix of these recommendations appears in Table 7-1, Medium Speed Diesel Recommended Practices, pages 7-25 through 7-41.

7.5.1 Cylinder Combustion Processes - Medium Speed Diesel

Unlike the slow speed diesels, much of the medium speed performance monitoring to date has been severely limited by lack of adequate instrumentation. New combustion monitoring techniques can provide reasonably accurate and repeatable data that heretofore have only been available on the test bed. As previously mentioned, the large quantity of cylinders and the probability of off-specification operation make this engine type a likely candidate for performance monitoring.

As pointed out in the two stroke, slow speed units, single air cooled or uncooled pressure transducers are suggested since multiple sensors are more costly and must endure permanent heat and pressure fluctuations. Rotary encoders or magnetic pick-ups are also recommended for deriving correct piston location. Again, as with the slow speed engines, calibration of this item must be performed correctly and carefully.

Details of these parameters are outlined in Table 7-1, Cylinder Combustion Processes, Medium Speed Diesels, page 7-25.

7.5.2 Fuel Injection Processes - Medium Speed Diesel

There are no medium speed engine manufacturers that have improved the use of injection pressure sensing on their engines. They are reluctant to authorize modifications to the high pressure fuel circuits. Due to this fact, and the uncertain diagnostic value of injection pressure sensing on these four stroke engines, this monitoring is not recommended. Strain gauges mounted external to the process may be a viable solution to this dilemma but they are not yet reliable or durable enough for this duty.

Cylinder cover temperature monitoring seems to be of dubious value on medium speed engines due to the lack of standardized comparison data and are also not suggested.

7.5.3 Air/Gas Path Processes - Medium Speed Diesel

The recommended standards outlined in Section 7.4.3 under slow speed diesels equally apply to these four stroke units.

See Table 7-1, Air Gas Path Processes, Medium Speed Diesel, Recommended Standards, pages 7-27 through 7-30 for specific guidance relative to monitored parameters.

7.5.4 Cylinder Components (Rings, Grooves, and Liners) Medium Speed Diesel

The most effective and practical method today for monitoring piston rings, grooves, liners and crowns for these medium speed engines is still visual inspection during engine disassembly.

Accordingly, no special monitoring equipment in these areas is recommended.

7.5.5 Air/Gas Path Components - Medium Speed Diesel

As previously discussed in Sections 7.4.3 and 7.4.5, coolers and filters can be effectively monitored by high accuracy, low drift pressure and temperature transmitters or local instrumentation.

Additionally, many of the same comments on turbochargers outlined in Section 7.4 are also valid for these medium speed engines.

Turbocharger bearings on medium speed, four stroke engines seem to be more of a problem than on the larger, slow speed units. Therefore, vibration monitoring is recommended

for each medium speed diesel turbocharger.

The suggestions regarding valve monitoring as described in Section 7.4.5 also hold true for these engines. Details of the recommended monitoring for these subsystems are contained in Table 7-1, Air/Gas Path Components, Medium Speed Diesel, pages 7-33 and 7-34.

7.5.6 Drive Train Bearing Components - Medium Speed Diesel

Drive train bearing casualties have been more prevalent in medium speed, four stroke engines than in the two stroke engines. Again, as mentioned in the slow speed section, a multi-faceted approach is necessary for adequate monitoring. Both main bearing and crank pin bearing shell metal temperatures should be monitored by imbedded RTD's. Oil mist monitors and crankweb deflection readings should be utilized regularly.

Since these trunk-type engines are more susceptible to lube oil degradation and contamination, regular lube oil analysis including ferrographic monitoring is recommended. Excessive lube oil acidity and additive depletion should also be controlled by regular sampling, analysis, and treatment. Appropriate detergent-dispersants and acid neutralizers should be added at regular intervals.

The recommended standards are outlined in Table 7-1, Drive Bearing Components, Medium Speed Diesel, pages 7-35 and 7-36.

7.5.7 Heat Exchanger Components

The comments outlined in Section 7.4.7 also apply to these medium speed units. See details in Table 7-1, Heat Exchanger Components, Medium Speed Diesels, page 7-7-37 through 7-38.

7.5.8 Fuel Oil Delivery Components - Medium Speed Diesel

The suggestions outlined in Section 7.4.8 are also applicable to these four stroke units. Table 7-1, Fuel Oil Delivery Components, Medium Speed Diesel, page 7-39 lists specific recommendations.

7.6 Use of Tables

Table 7-1 presents a detailed set of recommended standards for the application of diagnostic equipment to both slow speed and medium speed diesel propulsion plants.

The parameters are individually identified and presented in tabular form. Each subsystem has been outlined with supporting rationale in Sections 7.0 and 7.5.

Figure 7-1 provides a listing of the abbreviations and symbols utilized in Table 7-1.

FIGURE 7-1

LIST OF ABBREVIATIONS AND SYMBOLS USED IN TABLE 7-1

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
ANEM	Anemometer	MFGR "B" & "E"	Manufacturers B & E from Section 3.0
BLR	Waste Heat Boiler	MAN	Manometer
BRG	Bearing	MIP	Mean Indicated Pressure
CALC	Calculated	MPP	Magnetic Proximity Probe
CLR	Cooler	MPSR	Magnetic Probe w/Special Rings
CYL	Cylinder	NA	Not Applicable
DIG	Digital	NR	Not Required
DFGI	Draft Indicator	NCTC	Nickel Chromel/ Thermocouple
Δ	Differential	PO	Print Out
ENG	Engine	PT	Pressure Transmitter
ER	Engine Room	PG	Pressure Gage
FM	Flow Meter	RE	Rotary Encoder
FR	Fuel Rack	REMG	Remote Gauge/Ind.
FLTR	Filter	RTD	Resistance Temperature Detector
HSET	High Speed Electronic Tach	TG	Temperature Gage
HYGR	Hygrometer	TC	Thermocouple
HTR	Heater	TM	Torque Meter
LOG	Log Sheets		
LOCG	Local Gage or Indicator		
MFGRS "A" & "D"	Manufacturers A & D from Section 3.0		

FIGURE 7-1

LIST OF ABBREVIATIONS AND SYMBOLS CONTINUED

Abbreviations/ Symbols	Description	Abbreviations/ Symbols	Description
SEP	Separator	ABS	Absolute
UPPT	Uncooled Piezoelectric Pressure Transducer	APPT	Air Cooled Piezoelectric Press. Trans.
VIBPU	Vibration Pick-Up	LIN	Liner
VISI	Visual Inspection	OMM	Oil Mist Monitor
VISC	Viscometer	T/C	Turbocharger
WTH	Wireless Thermistor	STK	Stack
XDCR	Transducer	+	and
/	Or		

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
1	CYLINDER COMBUSTION PROCESSES	Pmi/or MIP	MEAN INDICATED PRESSURE (per cylinder)	1/ENG	UPPT/ APPT	DIG + PO	1/ENG	UPPT/ APPT	DIG+ PO	
2										
3		P_{max}	MAXIMUM OR FIRING PRESSURE (per cylinder)	1/ENG	UPPT/ APPT	DIG + PO	1/ENG	UPPT/ APPT	DIG + PO	
4		P_{comp}	COMPRESSION PRESSURE (per cylinder)	1/ENG	UPPT/ APPT	DIG + PO	1/ENG	UPPT/ APPT	DIG + PO	
5		P_{exp}	EXPANSION PRESSURE (per cylinder)	NR	NR	NR	1/ENG	UPPT/ APPT	DIG + PO	TYPICALLY MEASURED AT 36° AFTER TDC
6										
7		$\propto P_{max}$	ANGLE OR TIME OF P_{max} (per cylinder)	1/ENG	MPP OR RE	DIG + PO	1/ENG	MPP OR RE	DIG + PO	EXACT ALIGNMENT & CALIB. CRITICAL
8		$\propto P_{comp}$	ANGLE OR TIME OF P_{comp} (per cylinder)	1/ENG	MPP OR RE	DIG + PO	1/ENG	MPP OR RE	DIG + PO	EXACT ALIGNMENT & CALIB. CRITICAL
9										
10		RPM	SPEED AT ENGINE FLYWHEEL	1/ENG	MPP OR RE	DIG + PO	1/ENG	MPP OR RE	DIG + PO	
11		T/BHP	TORQUE/BHP AT ENGINE (value, method & location)	NA	FR/TM /MIP	DIG + PO	NA	FR/TM /MIP	DIG + PO	
12		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ENG	PT	DIG + PO	1/ENG	PT	DIG + PO	

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
				SENSOR			SENSOR			
		SYMBOL	DESCRIPTION	QTY	TYPE	DISPLAY	QTY	TYPE	DISPLAY	
13	FUEL INJECTION PROCESSES	POS & % DROOP	FUEL GOVERNOR POSITION AND % SPEED DROOP	1/ENG	VISI	NR	1/ENG	VISI	NR	
14		INDEX	FUEL PUMP INDEX (per cylinder)	1/CYL	VISI	NR	1/CYL	VISI	NR	
15										
16		$T_{cyl\ cover}$	CYLINDER TOP COVER TEMPS (per cylinder)	NR	NR	NR	NR	NR	NR	
17		P_{rise}	PRESSURE RISE PRIOR TO OPENING OF INJ. VLV (per cylinder)	NR	NR	NR	NR	NR	NR	
18		P_{injo}	DYNAMIC OPENING PRESS OF INJ VLV (per cylinder)	NR	NR	NR	NR	NR	NR	
19		P_{injm}	MAXIMUM INJECTION PRESSURE (per cylinder)	NR	NR	NR	NR	NR	NR	
20										
21		T_{injo}	TIME OF OPENING OF INJECTION VLV (per cylinder)	NR	NR	NR	NR	NR	NR	
22		L_{injo}	LENGTH OF OPENING OF INJ. VLV (per cylinder)	NR	NR	NR	NR	NR	NR	
23										
24										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
25	AIR/GAS PATH PROCESSES									
26		P_{baro}	ENGINE ROOM BAROMETRIC PRESSURE	1/ER	ABS PG/ MAN	LOGG	1/ER	ABS PG/ MAN	LOGG	
27										
28		$T_{E.R.}$	ENGINE ROOM AMBIENT TEMPERATURE	1/ER	TG	LOGG	1/ER	TG	LOGG	
29										
30		H_{rel}	ENGINE ROOM RELATIVE HUMIDITY	1/ER	HYGR	LOGG	1/ER	HYGR	LOGG	
31										
32		ΔP_{air}	AIR PRESSURE DROP ACROSS T/C SCAV INLET FILTER (per T/C)	1 per T/C	Δ PT/ MAN (1)	LOGG OR REMG	1 per T/C	Δ PT/ MAN(1)	LOGG OR REMG	(1) $\pm$ 1% ACCURACY/ LOW DRIFT
33										
34		Pcompr inlet	T/C COMPRESSOR INLET SUCTION PRESSURE (per T/C)	1 per T/C	ABS PG/ PT(1)	LOGG OR REMG	1 per T/C	ABS PG/ PT(1)	LOGG OR REMG	(1)
35		ΔP_{compr}	AIR PRESSURE DROP ACROSS T/C COMPRESSOR HOUSING (per T/C)	1 per T/C	Δ PT/ MAN(1)	LOGG OR REMG	1 per T/C	Δ PT/ MAN(1)	LOGG OR REMG	(1)
36		Pcompr outlet	AIR PRESSURE AFTER T/C COMPRESSOR (per T/C)	1 per T/C	$PT_{(1)}$	LOGG OR REMG	1 per T/C	$PT_{(1)}$	LOGG OR REMG	(1)

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
37	AIR/GAS PATH PROCESSES	$P_{sw\ in}$	SEA WATER PRESSURE AT INLET TO COOLER	NR	NR	NR	NR	NR	NR	
38										
39		ΔP_{air}	AIR PRESSURE DROP ACROSS CHARGE AIR COOLER (per cooler)	1/CLR	ΔPT/ MAN(1)	LOGG OR REMG	1/CLR	ΔPT/ MAN(1)	LOGG OR REMG	(1) $\pm$ 1% ACCURACY/ LOW DRIFT
40		P_{scav}	SCAVENGING BELT AIR PRESSURE	1/ENG	PG/ PT (1)	LOGG OR REMG	1/ENG	PG/ PT (1)	LOGG OR REMG	(1)
41										
42		$P_{turb\ inlet}$	EXHAUST GAS PRESSURE BEFORE TURBINE (per T/C)	1 per T/C	PG/ PT (1)	LOGG OR REMG	1 per T/C	PG/ PT (1)	LOGG OR REMG	(1)
43		$P_{turb\ outlet}$	EXHAUST GAS PRESSURE AFTER TURBINE (per T/C)	1 per T/C	PG/ PT (1)	LOGG OR REMG	1 per T/C	PG/ PT (1)	LOGG OR REMG	(1)
44										
45		$P_{into\ boiler}$	EXHAUST GAS PRESSURE BEFORE WASTE HEAT BOILER	1/BLR	PG/ PT (1)	LOGG OR REMG	1/BLR	PG/ PT (1)	LOGG OR REMG	(1)
46		P_{out}	EXHAUST GAS PRESSURE AFTER WASTE HEAT BOILER	1/BLR	PG/ PT (1)	LOGG OR REMG	1/BLR	PG/ PT (1)	LOGG OR REMG	(1)
47		$\%CO_2$	EXHAST GAS PERCENT CO_2	NR	NR	NR	NR	NR	NR	
48		—	EXHAUST GAS CONDITION (opacity, etc.)	1/STK	VISI	VISI	1/STK	VISI	VISI	

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR		DISPLAY	SENSOR		DISPLAY	
				QTY	TYPE		QTY	TYPE		
49	AIR/GAS PATH PROCESSES	T air in compr	AIR TEMP AT INLET TO T/C COMPRESSOR (per T/C)	1 per T/C	TG/ RTD(1)	LOCG OR REMG	1 per T/C	TG/ RTD(1)	LOCG OR REMG	(1) ± 1% ACCURACY/ LOW DRIFT
50		T air from compr	AIR TEMP AT OUTLET OF T/C COMPRESSOR (per T/C)	1 per T/C	TG/ RTD(1)	LOCG OR REMG	1 per T/C	TG/ RTD(1)	LOCG OR REMG	(1)
51										
52		T air in cooler	AIR TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD(1)	LOCG OR REMG	1/CLR	TG/ RTD(1)	LOCG OR REMG	(1)
53		T air from Clr	AIR TEMP AT OUTLET OF CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD(1)	LOCG OR REMG	1/CLR	TG/ RTD(1)	LOCG OR REMG	(1)
54										
55		T S.W. in Clr	SEA WATER TEMP AT INLET TO CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD(1)	LOCG OR REMG	1/CLR	TG/ RTD(1)	LOCG OR REMG	(1)
56		T S.W. out Clr	SEA WATER TEMP AT OUTLET FROM CHARGE AIR COOLER (per cooler)	1/CLR	TG/ RTD(1)	LOCG OR REMG	1/CLR	TG/ RTD(1)	LOCG OR REMG	(1)
57										
58		T_{scav}	SCAVENGING AIR BELT TEMPERATURE	1/ENG	TG/ RTD(1)	LOCG OR REMG	1/ENG	TG/ RTD(1)	LOCG OR REMG	(1)
59										
60										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
61	AIR/GAS PATH PROCESSES	$T_{exh\ indiv.}$	EXHAUST GAS TEMP AFTER CYLINDERS (indivual)	1/CYL	TC (1)	REMG	1/CYL	TC (1)	REMG	(1) ± 1% ACCURACY/ LOW DRIFT
62		$T_{exh\ mean}$	EXHAUST GAS TEMP AFTER CYLINDERS (mean)	1/ENG	CALC	REMG	1/ENG	CALC	REMG	
63		$T_{exh\ dev}$	EXHAUST GAS TEMP AFTER CYLINDERS (max. deviation)	1/ENG	CALC	REMG	1/ENG	CALC	REMG	
64										
65		$T_{exh\ to\ turb}$	EXHAUST GAS TEMP BEFORE TURBINE (per T/C)	1 per T/C	TC (1)	REMG	1 per T/C	TC (1)	REMG	(1)
66		$T_{exh\ out\ turb}$	EXHAUST GAS TEMP AFTER TURBINE (per T/C)	1 per T/C	TC (1)	REMG	1 per T/C	TC (1)	REMG	(1)
67		T_{in}	EXHAUST GAS TEMP BEFORE WASTE HEAT BOILER	1/BLR	TC (1)	LOCG OR REMG	1/BLR	TC (1)	LOCG OR REMG	(1)
68		T_{out}	EXHAUST GAS TEMP AFTER WASTE HEAT BOILER	1/BLR	TC (1)	LOCG OR REMG	1/BLR	TC (1)	LOCG OR REMG	(1)
69										
70		η_{turb}	TURBOCHARGER TURBINE EFFICIENCY	NR	NR	NR	NR	NR	NR	
71		η_{compr}	TURBOCHARGER COMPRESSOR EFFICIENCY	NR	NR	NR	NR	NR	NR	
72		η_{TC}	TURBOCHARGER OVERALL EFFICIENCY	NR	NR	NR	NR	NR	NR	

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
73	CYLINDER COMPONENTS (PISTON RINGS)	—	PISTON RING COLLAPSE	NR	VISI	NA	1/CYL	MPSR	PO	MFGRS "A" & "D" ONLY
							NR	VISI	NA	
74		—	PISTON RING BREAKAGE	NR	VISI	NA	1/CYL	MPSR	PO	MFGRS "A" & "D" ONLY
							NR	VISI	NA	
75		—	PISTON RING STICKING	NR	VISI	NA	1/CYL	MPSR	PO	MFGRS "A" & "D" ONLY
							NR	VISI	NA	
76		mm	PISTON RING WEAR	NR	VISI	NA	1/CYL	MPSR	PO	MFGRS "A" & "D" ONLY
							NR	VISI	NA	
77										
78		HRS	PISTON RING OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	
79	CYLINDER COMPONENTS (PISTONS)	—	PISTON GROOVE CONDITION	NR	VISI	NA	NR	VISI	NA	
80		mm	PISTON GROOVE WEAR	NR	VISI	NA	NR	VISI	NA	
81		—	PISTON CROWN CONDITION	NR	VISI	NA	NR	VISI	NA	
82		mm	PISTON CROWN WEAR	NR	VISI	NA	NR	VISI	NA	
83										
84		HRS	PISTON OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
85	CYLINDER COMPONENTS - LINERS	T_{Liner} (upper)	CYLINDER LINER TEMPERATURE (upper) (blowby)	NR	NR	NR	NR	NR	NR	MEASURED BTWN FIRST & SECOND RING
86										
87		T_{Liner} (lower)	CYLINDER LINER TEMP (lower) (skirt seizures)	NR	NR	NR	NR	NR	NR	
88		Tscuff	CYLINDER LINER TEMP (scuffing)	NR	NR	NR	NR 4/LIN	NR NCTC	NR REMI	 MFGRS "B"&"E" ONLY
89										
90		—	CYLINDER LINER CONDITION	NA	VISI	NA	NA	VISI	NA	
91		mm	CYLINDER LINER WEAR	NA	VISI	NA	NA	VISI	NA	
92		HRS	CYLINDER LINER OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	
93										
94		Kg/day	CYLINDER LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	
95		Kg/day	ENGINE LUBE OIL CONSUMPTION	NA	NA	LOG	NA	NA	LOG	
96										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
97	AIR/GAS PATH COMPONENTS (TURBOCHARGERS)	RPM	TURBOCHARGER SPEED (per T/C)	1 per T/C	HSET	REMG	1 per T/C	HSET	REMG	
98		mils	TURBOCHARGER VIBRATION LEVEL (per T/C)	1 per T/C	VIBPU	REMG	1 per T/C	NR	NR	PROPER PLACEMENT CRITICAL
99										
100		T L.O. in	TURBOCHARGER LUBE OIL INLET TEMPERATURE (per T/C)	1 per T/C	TG/ RTD	LOCG	1 per T/C	TG/ RTD	LOCG	
101		T L.O. out	TURBOCHARGER LUBE OIL OUTLET TEMPERATURE (per T/C)	1 per T/C	TG/ RTD	LOCG	1 per T/C	TG/ RTD	LOCG	
102		P L.O. in	TURBOCHARGER LUBE OIL INLET PRESSURE (per T/C)	1 per T/C	TG/ RTD	LOCG	1 per T/C	TG/ RTD	LOCG	
103										
104	AIR/GAS PATH COMPONENTS (EXHAUST VALVES)	mm	SPINDLE GUIDE CLEARANCES	← MANUAL MEASURE →						
105		mm	RING CLEARANCES	← MANUAL MEASURE →						
106		mm	SPINDLE WEAR	← MANUAL MEASURE →						
107		mm	SEAT WEAR	← MANUAL MEASURE →						
108										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
				SENSOR		DISPLAY	SENSOR		DISPLAY	
		SYMBOL	DESCRIPTION	QTY	TYPE		QTY	TYPE		
109	AIR/GAS PATH COMPONENTS-EXHAUST VALVES & GEAR	—	SEAT BURNING	NA	VISI	NA	NA	VISI	NA	
110		—	SPRING CONDITION	NA	VISI	NA	NA	VISI	NA	
111										
112		mm	HYDRAULIC LINER DIAMETER	← MANUAL MEASURE →						
113		mm	ROLLER CLEARANCES	← MANUAL MEASURE →						
114		—	CAM & ROLLER SURFACES	NA	VISI	NA	NA	VISI	NA	
115		—	HOUSING & GUIDE SURFACES	NA	VISI	NA	NA	VISI	NA	
116										
117		HRS	OPERATING HOURS	NA	NA	LOG	NA	NA	LOG	
118										
119										
120										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
121	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	MAIN BEARING OIL OUTLET TEMPERATURE	NR	NR	NR	$1/_{BRG}$	RTD	REMG	
122		T_{brg}	MAIN BEARING HOUSING AND SHELL TEMPERATURE	$1/_{BRG}$	RTD	REMG	NR	HR	HR	
123		mm	MAIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →						
124										
125		$T_{oil\ out}$	CRANK PIN BEARING OIL OUTLET TEMPERATURE	NR	NR	NR	$1/_{BRG}$	RTD	REMG	
126		T_{brg}	CRANK PIN BEARING HOUSING AND SHELL TEMPERATURES	$1/_{BRG}$	WTH	REMG	NR	NR	NR	WIRELESS SIGNAL TRANSMISSION
127		mm	CRANK PIN BEARING CLEARANCES	← MANUAL MEASUREMENTS →						
128										
129		$T_{oil\ out}$	CROSSHEAD BEARING OIL OUTLET TEMPERATURE	NA	NA	NA	$1/_{BRG}$	RTD	REMG	
130		T_{brg}	CROSSHEAD BEARING HOUSING AND SHELL TEMPERATURE	NA	NA	NA	NR	NR	NR	
131		mm	CROSSHEAD BEARING CLEARANCES	NA	NA	NA	MANUAL MEASUREMENTS			
132		mm	GUIDESHOE CLEARANCES	NA	NA	NA	MANUAL MEASUREMENTS			

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
133	DRIVE TRAIN BEARING COMPONENTS	$T_{oil\ out}$	THRUST BEARING OIL OUTLET TEMPERATURE	1/BRG	RTD	REMG	1/BRG	RTD	REMG	
134		T_{brg}	THRUST BEARING PAD METAL TEMPERATURE	NR	NR	NR	NR	NR	NR	
135		mm	THRUST BEARING PAD CLEARANCES	← MANUAL MEASUREMENTS →						
136		mm	CAMSHAFT BEARING CLEARANCES	← MANUAL MEASUREMENTS →						
137		ppm	CRANKCASE OIL MIST DETECTION	1/CYL	OMM	REMG	1/CYL	OMM	REMG	
138		mm	CONTROL DRIVE GEAR BACKLASH	← MANUAL MEASUREMENTS →						
139		—	LUBE OIL ANALYSIS (ferrography, etc.)	NA	LAB ANAL	NA	NR	NR	NR	WEAR AND CONTAMINATION ANALYSIS
140										
141		mm	CRANKSHAFT/MAIN BEARING DISPLACEMENT	← MANUAL MEASUREMENTS →						BRIDGE GAUGE
142										
143		mm	CRANKWEB DEFLECTION ANALYSIS	← MANUAL MEASUREMENTS →						DIAL GAUGE
144										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
145	HEAT EXCHANGER COMPONENTS - MAIN ENGINE	$\Delta T_{F.W.}$	JACKET WATER F.W. TEMP △ ACROSS JACKET WATER COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
146		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS JACKET WATER COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
147										
148		$\Delta T_{F.W.}$	PISTON COOLING F.W. TEMP △ ACROSS PISTON COOLER	NA	NA	NA	2/CLR	TG/RTD	LOCG or REMG	
149		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS PISTON COOLER	NA	NA	NA	2/CLR	TG/RTD	LOCG or REMG	
150										
151		$\Delta T_{L.O.}$	MAIN LUBE OIL TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
152		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS LUBE OIL COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
153										
154		$\Delta T_{L.O.}$	TURBOCHARGER LUBE OIL TEMP △ ACROSS T/C LUBE OIL COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
155		$\Delta T_{S.W.}$	SALT WATER TEMP △ ACROSS T/C LUBE OIL COOLER	2/CLR	TG/RTD	LOCG or REMG	2/CLR	TG/RTD	LOCG or REMG	
156										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
157	HEAT EXCHANGERS (MAIN ENGINE)	$\Delta T_{L.O.}$	CAMSHAFT LUBE OIL TEMP Δ ACROSS CAMSHAFT L.O. COOLER	NA	NA	NA	2/ CLR	TG/ RTD	LOCG or REMG	
158		$\Delta T_{S.W.}$	SALT WATER TEMP Δ ACROSS CAMSHAFT L.O. COOLER	NA	NA	NA	2/ CLR	TG/ RTD	LOCG or REMG	
159										
160			FRESH WATER COOLING ADDITIVE ADEQUACY	← MANUAL WATER ANALYSIS →						Ph AND SALINITY
161	HEAT EXCHANGER COMPONENTS (AUXILIARY ENGINES)	$\Delta T_{F.W.}$	AUX. ENG CYL FRESH WATER TEMP Δ ACROSS COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	
162		$\Delta T_{S.W.}$	SALT WATER TEMP Δ ACROSS FRESH WATER COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	
163										
164		ΔT_{air}	AUX ENG CHARGE AIR TEMP Δ ACROSS CHARGE AIR COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	
165		$\Delta T_{S.W.}$	SALT WATER TEMP Δ ACROSS CHARGE AIR COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	
166										
167		$\Delta T_{L.O.}$	AUX ENG LUBE OIL TEMP Δ ACROSS LUBE OIL COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	
168		$\Delta T_{S.W.}$	SALT WATER TEMP Δ ACROSS LUBE OIL COOLER	2/ CLR	TG/ RTD	LOCG or REMG	2/ CLR	TG/ RTD	LOCG or REMG	

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
169	FUEL OIL DELIVERY COMPONENTS	T f.o. htr	FUEL OIL TEMP BEFORE PREHEATERS	1/ HTR	TG	LOCG	1/ HTR	TG	LOCG	FOR BLENDED FUEL OIL
170		T F.O. vis.	FUEL OIL TEMP AFTER PRE-HEATERS AT VISCOMETER	1/ VISC	TG	LOCG	1/ ENG	TG	LOCG	FOR BLENDED FUEL OIL
171		T F.O. eng.	FUEL OIL TEMP AT ENGINE INLET	1/ ENG	TG	LOCG	1/ ENG	TG	LOCG	FOR BLENDED FUEL OIL
172										
173		P in fltrs	FUEL OIL PRESSURE BEFORE FILTERS	1/ FLTR	PG	LOCG	1/ FLTR	PG	LOCG	
174		P out fltr	FUEL OIL PRESSURE AFTER FILTERS AT ENGINE INLET	1/ FLTR	PG	LOCG	1/ FLTR	PG	LOCG	
175										
176		Q F.O.	FUEL OIL CONSUMPTION/ FLOW RATE	1/ ENG	FM	LOCG	1/ ENG	FM	LOCG	
177										
178		T in sep	FUEL OIL TEMPERATURE BEFORE SEPARATOR	1/ SEP	TG	LOCG	1/ SEP	TG	LOCG	
179		Q % flow	FUEL OIL PERCENT THROUGHPUT AT SEPARATORS	1/ SEP	FM	LOCG	1/ SEP	FM	LOCG	
180										

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
181	FUEL OIL DELIVERY COMPONENTS	cSt.	FUEL OIL VISCOSITY AT 50°C	← LAB ANALYSIS →						
182		S.G/ρ	FUEL OIL SPECIFIC GRAVITY OR DENSITY	← LAB ANALYSIS →						
183		% S	FUEL OIL SULFUR CONTENT	← LAB ANALYSIS →						
184		% V	FUEL OIL VANADIUM CONTENT	← LAB ANALYSIS →						
185		h_i	FUEL OIL HEATING VALUE	← LAB ANALYSIS →						
186										
187	VESSEL FACTORS - DESIGN	Ft/m	DRAFT (FWD/AFT) BALLAST	← DESIGN DATA →						
188		Ft or m	DRAFT (FWD/AFT) LADEN	← DESIGN DATA →						
189		DWT	DEADWEIGHT/BALLAST	← DESIGN DATA →						
190		DWT	DEADWEIGHT/LADEN	← DESIGN DATA →						
191		Knts	SPEED (LADEN/LIGHT)	← DESIGN DATA →						
192		mm	PROPELLER PITCH	← DESIGN DATA →						

Table 7-1

Recommended Diagnostic System Requirements

Medium Speed and Slow Speed Diesel Propulsion System

ITEM	SUB SYSTEM	MEASURED PARAMETER		MEDIUM SPEED DIESEL			SLOW SPEED DIESEL			REMARKS
		SYMBOL	DESCRIPTION	SENSOR QTY	SENSOR TYPE	DISPLAY	SENSOR QTY	SENSOR TYPE	DISPLAY	
193	VESSEL FACTORS - EXTERNAL	Ft/m	DRAFT (FWD/AFT)	2/SHIP	DFI	REMG	2/SHIP	DFI	REMG	
194										
195		knts	SPEED (by log)	1/SHIP	SPD LOG	REMG	1/SHIP	SPD LOG	REMG	
196		knts	SPEED (over ground)	NA	PLOT	VISI	NA	PLOT	VISI	(Observed)
197		min^{-1}	RPM (shaft/engine)	1/SHFT	TACH	REMG	1/SHFT	TACH	REMG	
198		%	PROPELLER SLIP	← CALCULATED →						
199										
200		Ft/m	WATER DEPTH	1/SHIP	XCDR	REMG	1/SHIP	XCDR	REMG	
201		#	SEA STATE	← OBSERVED →						
202		DIR	SEA DIRECTION	← OBSERVED →						
203		#	WIND FORCE	1/SHIP	ANEM	REMG	1/SHIP	ANEM	REMG	
204		DIR	WIND DIRECTION	1/SHIP	ANEM	REMG	1/SHIP	ANEM	REMG	

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